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ELECTRO-OPTICAL SYSTEMS, INC. Pasadena, California

Interim Summary Report for 1 November 1961 through 31 March 1962

RESEARCH AND DEVELOPMENT OF HIGH EFFICIENCY LIGHTWEIGHT SOLAR CONCENTRATORS

Prepared for

Headquarters
National Aeronautics and Space Administration
801 19th Street N.W., Room 526
Washington 25, D. C.
Attn: Mr. Walter Scott, Code DA

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Prepared by

M. A. Pichel
Project Supervisor

Approved by

Lee M. Springer, Manager
Engineering Development Dept.

Approved by

J. Neustein
J. Neustein, Manager
ADVANCED POWER SYSTEMS DIVISION

ELECTRO-OPTICAL SYSTEMS, INC. - PASADENA, CALIFORNIA

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ABSTRACT

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This report describes work performed during the 5-month period starting 1 November 1961 and ending 31 March 1962, under Contract No. NAS 7-86. This research and development contract is related to the development and improvement of techniques for fabrication of high efficiency, lightweight solar concentrators. The first portion of the program has been chiefly concerned with investigation of backing and support structures for 5-foot diameter concentrators and the evaluation of parameters relative to their application to concentrators of larger sizes. Stress has been placed on the design and structural approaches of electroforming and the application of this technique to the production of concentrators. Necessary special tooling required for the fabrication of 5-foot diameter concentrators has been designed and produced in preparation for experimental fabrication of units of this size during the remainder of the program.

A number of supporting and investigatory studies have been carried on relative to the parameters affecting the electroforming of a variety of materials suitable for use in concentrator fabrication, with emphasis on electroformed nickel and copper. Testing of the physical properties of electroformed samples made under a wide range of conditions has been initiated and it appears that a relatively wide variation in physical properties can be obtained on a controlled basis. Various reflective and protective coatings have also been investigated for use with concentrators produced by the electroforming process and their durability under various environmental conditions is in the process of being evaluated.

Author

1. INTRODUCTION

Electro-Optical Systems has, for a number of years, been intensely interested in solar energy conversion and has engaged in a number of study and developmental programs in this area. Since detailed information has already been set forth in the reports resulting from these prior activities, an extensive review will not be included here. The programs, resultant reports, and a brief description of the area of activity, are listed in the following paragraphs. A familiarity with the information contained in these past reports will be beneficial in the understanding and evaluation of the present area of activity.

Definitions of terminologies and descriptive phrases used in this report are contained in paragraph 1.5.

1.1 Review of Prior Concentrator Development at Electro-Optical Systems, Inc.

An extensive one-year effort, both analytical and experimental, concerned with the design and development of solar concentrators and their integration into space power systems, was performed by EOS for the Army Ballistic Missile Agency, Huntsville, Alabama, under Contract DA-04-495-506-ORD-1790. The program involved a comprehensive study covering a wide range of subjects including details of system design requirements and design data, basic concentrator design considerations, thermal energy converters, concentrator size requirements, and estimates ofsome component weights and dimensions. Concentrator structural and fabrication techniques were discussed and included elements of concentrator structure, concentrator design considerations, fabrication techniques, and materials. The experimental development phases of the program included fabrication of small-scale sample concentrators. A wide variety of fabrication processes were investigated to establish the advantages and disadvantages of each.

Explosive forming, spin forming, stretch forming, matched-dye forming, and other similar processes that were evaluated involved actual deformation and physical realignment of the skin material to conform with the forming die, tool, or mandrel used in the fabrication process In addition to this deformation and stretching of the material itself, the part was required to come in physical contact with the face of the mandrel or tool during the course of forming. As a result, it was found to be impossible to maintain the surface accuracy and polish required for high efficiency concentrator performance without repolishing after the forming process was completed. Subsequent polishing operations were found to be difficult, if not impossible, to carry out on the thin-skin structures that were required for achievement of very low specific weight (pounds per square foot of surface area). For these as well as other considerations, the formation of the concentrator reflector face skins by these more conventional methods was considered far from optimum; consequently, a better fabrication process was desired.

To eliminate the need for reforming or repolishing the concentrator reflective-face material, various techniques for producing a structurally sound, lightweight, highly reflective face skin by replicating an accurate master were considered. One of the most extensively developed techniques for such replication involves the use of plastic materials, both filled and unfilled, which obtain their structural integrity through the use of backing structures such as glass laminates and honeycombs. Unfilled plastic materials, both in the polyester and epoxy categories, were found to have the ability to reproduce surface characteristics very accurately and, with proper coatings, could exhibit reflectivities very nearly approaching those obtainable with coated glass. Unfilled plastic materials were found to be relatively unstable, however, and highly accurate geometries could not be maintained. These materials were also found to have very little strength in themselves and, as a consequence, proper backing structures were required for adequate support. Moreover, these materials may be subject to degradation due to ultraviolet radiation and other space factors. Filled plastic resins were relatively more stable, but were found to lose the ability to maintain good surface characteristics. The surfaces very often developed a minute "orange peel" effect that resulted in a definite loss of reflectivity.

During the course of extensive experimental evaluation of replicated plastic surfaces, rigidized by various means, a definite showthrough of the backing structure was experienced. Samples were prepared both by EOS and outside vendors employing various types of honeycombs, both metallic and non-metallic. Foams of varying densities and formulations were also evaluated. In all cases where thicknesses needed to produce structures with reasonable weights were used, showthrough and distortion were evident. In the case of honeycombed-backed structures, this showthrough appeared in the form of the cell structure of the honeycomb, and was caused by residual stress and shrink of the materials used to bond the backing structure to the reflective surface. In the case of foam backing, the distortion was not so clearly defined but progressed with time in the forming of an exaggerated and nonuniform "orange peel" effect. This condition was accelerated with large temperature changes and resulted in considerable loss in mirror efficiency.

The ability of plastic resins and related materials to withstand space environment has not at this time been satisfactorily demonstrated. The combinations of these various materials required to develop a suitable structure can result in heat transfer and other thermal characteristics that, in turn, can adversely influence the geometry of the structure. Although being unquestionably useful for some applications, these methods of fabrication (as was the case with methods involving reforming of metallic skins) were considered to have serious drawbacks for high-efficiency, long-life concentrators.

During the course of these investigations the process of replication by electroforming was also evaluated. This process appeared to offer solutions to many of the important problems inherent in other methods and made possible very accurate surface replication of the master. Extensive tests on electroforms replicated from optically ground and polished glass masters demonstrated reflectivity characteristics essentially identical with those of the master from which they were replicated. Moreover, it appeared possible to achieve, through further development and refinement of the process, reflective face skins and structural parts that would have low internal or residual stress. As a result, the geometry of the master should be reproduced accurately.

In order to fully evaluate the possibilities that the electroforming process seemed to offer, a number of electroformed reflective skins and structures were produced by outside vendors for evaluation. From these structures the ability of the electroforming process to produce reflective surfaces comparable to glass mirrors was verified beyond doubt. Problems existed, however, in two basic areas: (1) improvement and refinement of the state-of-the-art of electroforming was needed to gain greater control over stress characteristics and the physical properties of the electrodeposited material; (2) development of specific designs and fabrication techniques was required to allow the advantages offered by electroforming to be used to the fullest in concentrator fabrication. New techniques were required along with an extremely high degree of process control. As experience showed, these were not available in shops where practices have been formalized for many years.

As a consequence, EOS undertook the development of its own special capabilities and facilities for precision electroforming. Electroforming studies, coupled with advanced and novel designs and applications for the electroforming technique, resulted in the development of small-scale and 60-inch diameter concentrators having efficiencies approaching 90 percent, based on the concentration ratios required for high-temperature, high-performance systems such as solar thermionic power systems. The resultant structures proved the feasibility of fabricating solar concentrators by the electroforming process in such a manner that only a single material need be used. The reflecting face skin, supporting and rigidizing structure, brackets, points of attachment, etc., could all be produced from one common material as an integral structure without the need for adhesives, welds, brazes, or the like. With proper controls over the fabrication process, high reflectivity and accurate control of geometry could be achieved. Other advantages would be gained, including uniformity of thermal characteristics and stability in space environment as opposed to structures employing combinations of materials.

Details of these investigations and the related experimental developments are recorded in the first phase technical summary report, EOS Report 410-Final, dated 16 May 1960, and in the final report, EOS Report 410-Final II, dated 11 December 1960. Both of these reports were produced as a result of the work performed under Contract DA-04-495-506-ORD-1790.

In order to continue the development work undertaken initially for the Army Ballistic Missile Agency, a research and development program was undertaken by EOS for the National Aeronautics and Space Administration under Contract NAS 7-10. This work was performed over a period of one year, commencing 1 November 1960 and ending 31 October 1961. Specific investigations and supporting experimental developments were undertaken in a number of related areas with the goal of developing the necessary supporting knowledge, techniques, and related equipment to produce and evaluate lightweight, high efficiency solar concentrators.

Basic electroforming studies were continued with emphasis on determination and control of parameters affecting stress and physical properties in such a manner that these parameters and advanced techniques could be applied to actual fabrication processes. Areas of investigation included the development of necessary instrumentation to determine the existence and magnitude of inherent stress in the electroforms, methods of determining and controlling variations in current density, effects of additives and contaminants on the characteristics of the solution and resulting electroforms, and methods of determining effects of, and controls for, variations in agitation, temperature, etc. In addition to this main area of developmental work as related to nickel electroforming, the use of copper having improved structural properties was also evaluated and the deviations from nickel techniques determined. Investigations were also performed relative to the use of various master materials, the choice and use of sensitizing and reflective coatings for non-metallic masters, and their effect on parting of the replica from the master itself.

Master fabrication techniques were investigated for use in conjunction with electroformed concentrators. This phase of the program also included an investigation of scaling problems. Master surfacing materials were evaluated and tested experimentally to determine the reflectivity and the stability of geometry which could be expected. A model master was developed to demonstrate feasibility of the design and fabrication technique that would be used to generate desired geometry and surface conditions. Methods used in the fabrication of the model master demonstrated necessary tooling and equipment, fabrication, grinding and polishing processes. A test plating of a replica was made from the model master to check surface polish and determine if any parting problems existed.

Concentrator design concepts were formalized and evaluated relative to their compatibility with the electroforming process. Designs considered included reflective skins rigidized by a peripheral torus, as well as other structural concepts, including those which would be applicable to segmented as well as one piece concentrators. Small scale experimental fabrication was undertaken to determine the feasibility of employing particular design concepts in actual production, and to determine the problem areas related to tooling, electroforming, and other practical fabrication problems. In conjunction with the small scale concentrator development, techniques for fabricating various substructures such as ribs, struts, and brackets were developed.

In order to adapt these techniques for application to concentrator sizes that would be representative of those sizes which might be employed in space power systems, the more feasible of the small scale models was scaled and made in a 60-inch diameter size so that problems associated with parting, handling, surface coating, etc., could be evaluated directly. A number of 60-inch units were produced experimentally and sectioned to determine uniformity of plating and integrity of structure, etc. Two additional 60-inch units made entirely of electroformed nickel, and representing the finalized design and fabrication concepts, were produced for delivery to JPL for further evaluation.

Although the development of techniques for producing electroformed copper having improved physical characteristics was not as advanced as for nickel electroforming, an all copper, torus-rigidized 60-inch diameter concentrator was produced to determine the problems associated with working with this material in the larger sizes. The same design concepts and tooling,which were employed to produce the 60-inch nickel concentrators,were used in production of the copper unit.

In order to adequately evaluate the concentrators produced under the program a series of testing procedures was developed and the necessary supporting equipment and testing techniques perfected. These included development of tests to determine and evaluate both qualitatively and quantitatively, if possible, the accuracy of geometry and the quality of the reflective surface. One of the most critical areas of testing involved the use of calorimetry. Consequently, equipment and techniques were developed for accurate calorimetric test procedures which were applicable for concentrator testing. Each concentrator produced under the contract was evaluated using the techniques developed.

The first all-electroformed nickel 60-inch concentrator achieved efficiencies ranging from 55.6 percent at a 1/2-inch calorimeter aperture diameter to 88.3 percent at 1 inch aperture diameter. This concentrator underwent a rather extensive shake and vibration survey at JPL and the resultant information was fed back to produce modifications and improvements in subsequent models. The second nickel concentrator produced efficiencies which ranged from an average of 64 percent at the 1/2-inch aperture size to approximately 93 percent at 1-3/4 inch aperture size. The copper concentrator, which had a badly degraded reflective surface due to oxidation of the copper reflective face prior to application of the reflective coating, produced efficiencies averaging approximately 60 percent at 1/2-inch orifice size and 77.5 percent at 2-inch aperture size.

Results of these performance tests indicated conclusively that performance levels could be achieved using this method of construction, which were far higher than those demonstrated using any other fabrication techniques.

Extensive details of these investigations and related experimental developments were recorded in the final technical summary report, EOS Report 1587-Final, dated 27 December 1961.

1.2 Summary of Program Goals

The developmental work performed during the course of the prior programs demonstrated conclusively the feasibility of producing solar concentrators entirely by the electroforming process. It became apparent that to achieve the desired goals, the electroforming process must be carried out under a high degree of control with specific areas of development required. In order to achieve rapid improvement in concentrator design fabrication techniques so that high performance concentrators fabricated by use of the electroforming process can be considered "flight hardware" within a relatively short span of time, a number of specific areas of activity were set forth for evaluation and experimental development during the course of the present program. These areas are as follows:

1.2.1 Backing Structure Studies

Backing structure studies would be undertaken in which various concepts for backing or support structures for 5-foot diameter mirrors would be investigated, and the various parameters analyzed relative to their application to larger sizes of concentrators. In conjunction with this, small scale experimental studies of support structures were to be conducted to include an experimental evaluation of backing masters, support structure and attachment methods, experimental application of the more promising design concepts, and the possible effects of tensile or compressive plating stresses on the characteristics of the concentrator reflector face and backing structure.

In the course of the experimental development a number of representative mirrors approximately 17 to 18 inches in diameter would be fabricated and at least two 5-foot diameter mirrors would be fabricated using nickel electroforming techniques that would demonstrate the most promising methods as developed in the smaller experimental sizes. These mirrors, or major portions thereof, would be sectioned or otherwise destructively tested to determine soundness of fabrication techniques and ultimate strength capabilities.

In addition, two 5-foot diameter mirrors would be fabricated, using the nickel electroforming process. These would demonstrate the most promising design and fabrication techniques. Necessary special tools and fixtures required for fabrication of the more advanced structures would be designed and fabricated. These would include a rotator capable of handling 5-foot diameter and larger masters, necessary handling fixtures, specially shaped anodes and masks, special mandrels, master extensions, and other devices associated with more sophisticated design concepts.

The two final 60-inch nickel concentrators would be subjected to optical and performance tests prior to delivery to the Jet Propulsion Laboratory for further optical and performance testing and shake and vibration evaluations.

Upon conclusion of the experimental and design phases of the program the various parameters would be summarized and recommendations made regarding backing structure designs.

1.2.2 Plating Techniques

Development of plating techniques for the fabrication of electroformed nickel and copper mirrors and mirror structures would be continued, and include small-scale studies relative to the improvement of physical properties of nickel and copper electroforms, reduction and control of plating stress in nickel and copper mirrors, development of techniques for monitoring and determining additive concentrations in plating solutions and the possible use of chromium for improvement of structural and, more particularly, surface properties of nickel and copper mirrors.

Physical testing of various plated samples would be accomplished and would include, if necessary, the development and construction of special testing devices to measure important physical properties. A major objective of this work is to increase the knowledge of copper-plating techniques to a level approaching that of nickel.

At least one 5-foot diameter mirror would be fabricated using the electroformed-copper techniques so that sectioning or destructive testing could be accomplished to produce a feedback for improvement of design or fabrication techniques. At the conclusion of this developmental phase at least one additional 5-foot diameter concentrator would be fabricated using the electroformed-copper techniques that would demonstrate the most promising design and fabrication concepts associated with use of this material. Optical and performance tests would be made on this mirror before delivery to JPL for further testing and evaluation.

At the conclusion of the program the various parameters affecting electroforming of the various materials would be summarized and recommendations made regarding these techniques and processes.

1.2.3 Advanced Coating Studies

Advanced coating studies would be made and would include small-scale evaluations of problems related to substrate and master characteristics, the development of surface coatings for maximum reflectivity, an evaluation of coating durability, including development of devices for measuring coating adherence, if possible, and for mirror handling and cleaning. The mechanics of coating deposition would also be demonstrated and these techniques applied to the coating of the small and large mirrors to be fabricated during the course of this contract.

In addition, at the conclusion of the experimental phase of the program, recommendations concerning facilities for coating large concentrators would be made.

The above categories are, in some instances, rather gen. al. Close contact, on a technical basis, will be maintained with the technical monitors at JPL during the course of the program so that critical areas or areas of particular interest can be expanded or minimized to produce the maximum amount of information obtainable within the scope of the program. Specific details not mentioned in this summary of program goals will be outlined in the body of this interim report or in the final technical summary report.

1.3 Program Schedule

The general program schedule showing the different areas of activity is shown in Fig. 1-1. The first five-month period of the program has been involved with design concepts and small-scale experimental studies as shown. Fabrication of the various 60-inch concentrators, testing of these concentrators, and application of the most desirable reflective and protective coatings will be accomplished during the second and final phase of the program.

1.4 Summary of Report

This report covers all phases of the work performed during the first five-month period of this program commencing 1 November 1961 and ending 31 March 1962. As was the case in past programs of this nature, considerable interaction occurred between the different areas of activity. For clarity, however, in this report, the three basic areas of activity indicated in the program schedule (Fig. 1-1) are presented in separate sections.

Section 2 contains information relative to the investigation of the backing and support structures for 5-foot diameter concentrators, a preliminary discussion as to their application to larger sizes, and information on the small-scale experimental studies. Preliminary design concepts and developmental work associated with the 5-foot diameter sizes in which rear-mounted tori are used for mounting and support are also discussed.

Section 3 contains a description of the development of improved plating techniques. Small-scale studies are discussed and include a description of the methods for solution analysis and controls, stress determination in both nickel and copper electroforms, the use of chromium and rhodium as surfacing materials, and an evaluation of the physical properties of electroformed materials produced by variations in the electroforming parameters.

Section 4 discusses the experimental work associated with advanced coating studies. Small-scale studies performed include an evaluation of the effects of master on substrate materials, an experimental survey of the various high-reflectivity coatings, adhesion and durability studies, a preliminary approach to protection and cleaning techniques, and a preliminary evaluation of the application of selected coatings on mirrors to be produced during the course of this program.

Since no 5-foot diameter concentrators were completed during this first five-month period and optical performance tests could not be made, complete testing results will be included in the final technical summary report.

1.5 Definitions

The use of new techniques, processes, and designs has necessitated the development of new terminologies and descriptive phrases. Since varying terminologies are sometimes used by those engaged in these activities, and in order to clarify the reading of this report for those who are not familiar with these terminologies, the following set of definitions is presented and will be used throughout:

a. Concentrator (or mirror)

The reflecting device used to concentrate solar radiation into a focal zone.

b. <u>Concentrator Face (or face skin)</u>

The reflective face of the concentrator.

c. <u>Backing (or rigidizing structure)</u>

That part which supports and holds the reflective face skin, to preserve the as-formed geometry of the reflective face skin.

d. <u>Monocoque Structure</u>

A type of single structure or shell that forms, and includes, the reflective face and the rigidizing or backing structure as one unit. This structure may be either a mirror segment or a complete mirror.

e. <u>Original Mirror</u>

A concave mirror from which masters or replications may be formed.

f. <u>Mirror Master</u>

A fixture, normally convex, having the required degree of surface quality and finish, together with necessary geometrical accuracy, from which the concentrator face skin may be formed by a replication process. Masters may represent an entire mirror surface, a segment, or a section of the entire surface. They may be fabricated separately (original masters) to specification, or produced by replicating (replicated masters) the surface and geometry of an original mirror or mirror segment.

g. <u>Replica Mirror</u>

Mirrors formed by the replication process using electroforming or other techniques. These can be formed either from original masters or replicated masters.

h. <u>Mandrels (or molds)</u>

Structures produced by a variety of methods on which material is electrodeposited to produce a finished electroform to a predetermined and desired shape.

i. Current Density

An electroforming term referring to the number of amperes per square foot of area being electroformed. Usually an average value is quoted.

j. Inherent Stress

Electroforming terminology referring to the stresses developed in the electrodeposited material during the plating process. These stresses may be either tensile or compressive in nature.

k. Concentrator Specific Weight

The total weight of concentrator divided by projected surface area. In this report the specific weight will be expressed in pounds per square foot.

l. Specular Reflectivity

That portion of the incident energy which is reflected at an angle equal to the angle of incidence.

m. Concentration Efficiency

The ratio of the total power (solar radiation) delivered to a given absorber orifice to the total power incident on the mirror. The concentration efficiency is a function of mirror geometry, surface characteristics, and magnitude of specular reflectivity.

n. Concentration Ratio

The ratio of the projected area of the mirror surface to the area of the focal zone into which the energy incident on the mirror is focused.

FIGURE 1-1 PROJECT SCHEDULE

Project WA 2100

I. BACKING STRUCTURE STUDIES

A. Investigation of backing and support structures for 5 ft. dia. concentrators and application to larger sizes - continuing effort

B. Small scale (18" dia.) experimental studies and fabricating including evaluation of:
   1. Backing master considerations
   2. Support structure attachment methods
   3. Evaluation of various concepts
   4. Effects of plating stresses on structures
   5. Delivery of representative models

C. 5 ft. dia. concentrator development
   1. Development of tooling including rotational device for agitation, handling fixtures, special tooling, mandrels, etc.
   2. Delivery of items IC-1
   3. Fabrication of two (2) 5 ft. dia. nickel concentrators to be destructively investigated (sectioning, shak and vibration, etc.)
   4. Fabrication of two (2) 5 ft. dia. nickel concentrators of most promising design
   5. Performance testing and evaluation of optical characteristic of Items IC-4
   6. Delivery of items IC-4
   7. Shake and vibration testing of items IC-4 (Jet Propulsion Laboratory function)

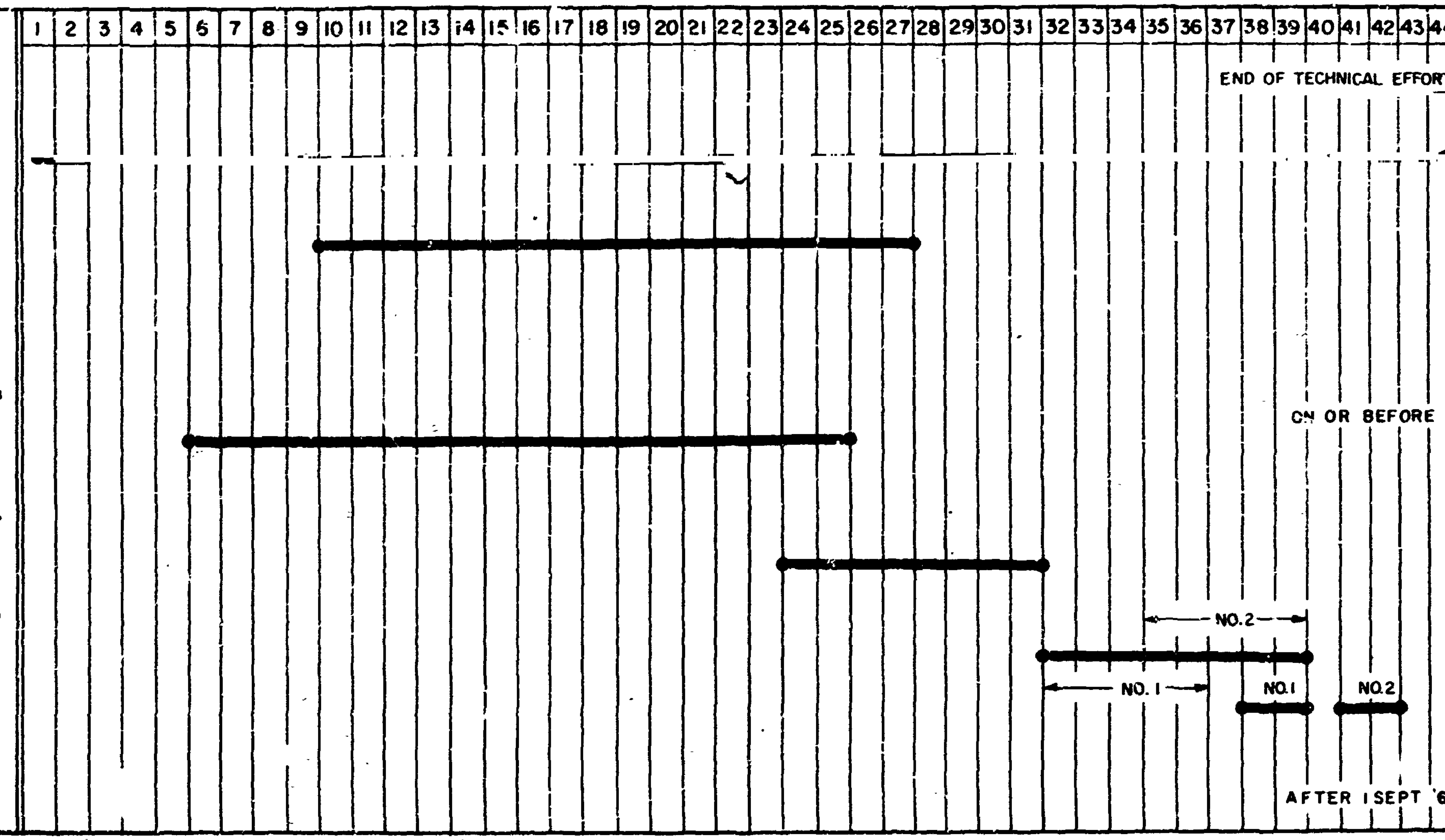


FIGURE 1-1 (cont)

II DEVELOPMENT OF PLATING TECHNIQUES FOR FABRICATION OF ELECTROFORMED NICKEL-COPPER MIRRORS

A. Small scale studies including investigation of: physical properties, control of stress, solution control, use of chromium for surfacing

B. Physical testing of plated samples

C. Development of 5 ft. dia. copper concentrator

1. Fabrication of one (1) unit to be destructively investigated
2. Fabrication of one (1) unit of most promising design and technique
3. Performance testing and evaluation of optical characteristics of item IIC-2
4. Delivery of item IIC-2
5. Shake and vibration testing of item IIC-2 (Jet Propulsion Laboratory function)

III ADVANCED COATING STUDIES

A. Small scale studies of:

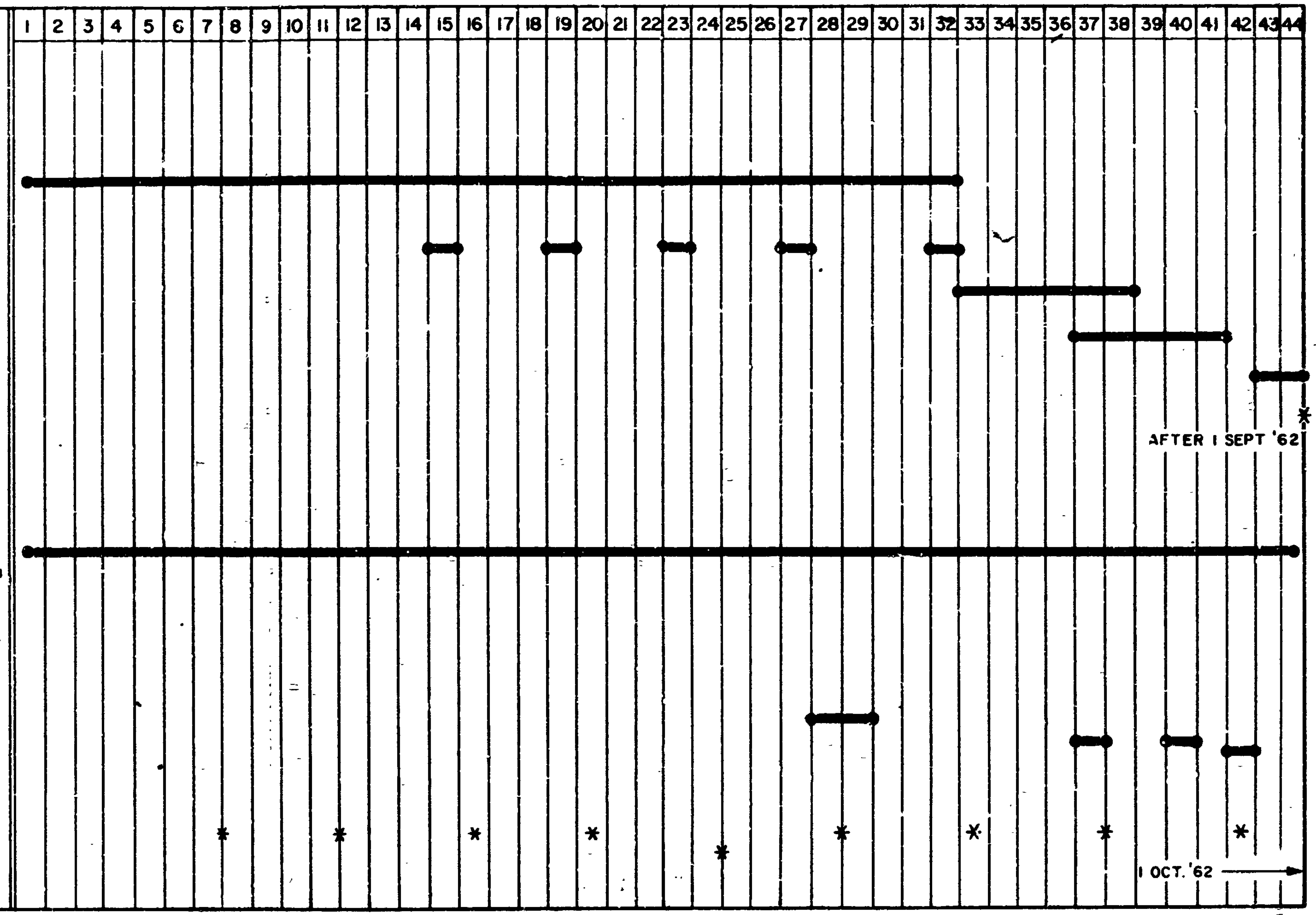
1. Effects of substrate and master characteristics
2. Surface coatings for high reflectivity
3. Coating durability, degradation, cleaning and protective techniques
4. Mechanics of coating

B. Application of selected coatings to concentrators produced during program

1. Small scale concentrators - IC-4 (2 units)
   IIC-2 (1 unit)

IV REPORTS

A. Monthly letter reports
B. Interim summary report
C. Final technical report



2. BACKING STUDIES

There is very little information applicable to backing the extremely thin metallic skins required for solar concentrator reflector faces in a manner that produces no showthrough or optical distortion. A considerable amount of survey and experimental evaluation has been conducted in the past to determine the best possible methods for such backing or rigidizing.

Since the current program has as its objective the development of all-electroformed structures that do not incorporate welds, adhesives, or other such joining techniques, the types of backings to be considered are further limited to those that can be formed by electroforming or a compatible process so that attachments can be accomplished by electroforming. Small-scale samples are informative in that their use immediately eliminates those techniques that are not compatible due to reasons of showthrough, or severe degradation of reflective surface.

Techniques that appear applicable are best demonstrated in larger sizes such as 5-foot diameter concentrators. This size enables the application of fabrication and joining techniques that could not be performed on extremely small samples. A skin thickness-curvature-total diameter relationship can result that can actually be tested structurally and from which, it is hoped, information can be obtained that will allow scaling to larger sizes. The main area of activity related to backing structures during the course of this program will be concerned with 5-foot diameter sizes, although other variations or novel approaches will be investigated experimentally on a smaller scale. The application of the resultant techniques to concentrators larger than 5 feet in diameter will also be evaluated.

2.1 Investigation of Backing and Support Structures for 5-Foot Diameter Concentrators

A complete evaluation of the various types of backing and support structures available for 5-foot diameter concentrators cannot be made until later in the program when a variety of different techniques and approaches have been evaluated experimentally. Preliminary studies, however, have shown that the rim, or outside support, is considerably more desirable than center support for a number of reasons.

Comparisons indicate that maximum support and rigidity can be gained with minimum structural weight when peripheral support is used. The development of structural techniques and designs of concentrators should not, and cannot, ignore the fact that in application an absorber, or a cavity of some sort, will be required to be positioned and supported at the focal zone. For high performance systems the support must provide accurate and stable positioning for the absorber or cavity within a very few thousandths of an inch.

Absorber supports that are positioned from the center of the concentrator will necessarily intercept the reflected solar flux between the mirror and the absorber. In this position the converging cone of light is extremely concentrated as compared to the solar flux falling on the mirror surface. The total amount of energy lost through obscuration of the struts or absorber supports is far greater per unit area than that which would be lost due to the same obscurity in the unconcentrated state. It appears difficult to design the necessary absorber supports to allow sufficient minimization of obscuration and still provide the necessary stability and strength required for adequate mounting.

In comparison with this condition, collector or cavity supports of a tripod or similar design that are attached to the periphery or rim of the concentrator provide maximum accuracy and structural support for the absorber at the focal point. They also provide minimum possible obscuration since they intercept the solar flux prior to concentration. Positioning of the absorber supports at the periphery or rim necessitates that this portion of the concentrator be structurally sound and stable. When a peripherally supported concentrator design is employed in which points of attachment to vehicle or mounts are at the rim and preferably in the same location as the absorber supports (as demonstrated in prior concentrators produced by EOS), maximum stability and support is gained without the need for the remainder of the concentrator structure to support any of its own weight. It is obvious that if the concentrator were center supported and the more desirable rim-mounted absorber support method were used, the load would have to be transferred from rim to center of mirror by relatively heavy structural members. This configuration would be, although acceptable, considerably heavier than the totally rim-supported configuration.

At this point, the peripheral torus design incorporating mounting points for both vehicle attachment and absorber support structures appears to be the most desirable. Further information that will result from shake and vibration testing of previously fabricated structures will be required to finalize designs for this size, and no further discussion will be included at this time.

2.2 Application to Larger Sizes

Preliminary investigation of the stability of electroformed skins and the different relationships of thickness, physical properties of the electroform itself, rate of curvature, etc., that would be associated with one-piece concentrators of the same design concept expanded to larger diameters, indicate that this technique will be applicable to considerably larger units. The skin-thickness to rate-of-curvature ratio is a very critical aspect. One-piece concentrators provide an ideal symmetrical configuration, and maximum strength-to-weight ratios should be achieved with this configuration.

No attempt will be made at this time to outline detailed parameters affecting scaling. This information will be accumulated from evaluation of experimental results during the remainder of the program and will be covered in detail in the final report.

2.3 Small-Scale Experimental Studies

A number of small-scale experimental studies have been carried on during the first 5-month period of the program. Experimental work has been accomplished using approximately 18-inch diameter glass convex masters having approximately the same focal length-to-diameter relationship as the 5-foot concentrators in question.

2.3.1 Backing Master Considerations

A variety of backing concepts were considered during the early stages of the program for backing or rigidizing electroformed face skins. As previously mentioned, the center supported configurations were discarded due to their inherent limitations. This eliminated the concept of the fully enclosed monocoque-type structure for one-piece mirrors. The principle objective of the present program has been to provide backing and support structures in a configuration that would provide maximum usable reflective surface of the mirror. Since the complete monocoque was eliminated it appeared that rear-mounted variations of the torus or modified monocoque-type configuration would be capable of providing the necessary structural rigidity and points of attachment. A number of variations were considered and applied experimentally in a small scale. Since the torus technique was chosen for evaluation, backing masters as such were not required. Special tooling and mandrels that would be required for application of the torus to the rear of the concentrator reflective skin in actual fabrication of the 5-foot diameter concentrators will be reviewed separately.

For larger size concentrators requiring intermediate points of support of the reflective skin, backing masters of some description would be required to permit electroforming of the various components. Since the governing or limiting parameters of unsupported span, skin thickness, physical properties, etc., have not been fully determined at this time, backing-master requirements cannot be established. There are a number of materials and techniques that are applicable to producing backing masters of any required configuration when design concepts are more fully established.

2.3.2 Support Structure Attachment Methods

Various methods of attaching the rear-mounted torus to the reflector-face skin were considered. A number of variations exist, but the most desirable from the standpoint of applicability to the electroforming process are shown in Fig. 2-1. Among the proven attachment methods, an encapsulation lock provided by the chain or wire technique, and secondary plating using the electroformed riveting technique, appear to be the most promising. In application, the convex master is modified at the rim, depending upon which method is chosen, and the reflective-face skin electroformed with the necessary rim or encapsulation locking devices. The torus, which for experimental purposes is merely a formed tube, is positioned in back of the reflective-face skin and the necessary mandrels for attachment are hand formed of wax or other removable materials. Secondary plating is then accomplished, providing structural attachment and bonding of the torus to the reflective-face skin.

2.3.3 Evaluation of Various Concepts - Experimental Fabrication

A number of experimental fabrications were accomplished using an 18-inch diameter glass master. Although basic techniques have already been demonstrated, a number of minor problems existed relative to the utilization of these techniques. If secondary plating is to be used, provisions must be made to control or allow for differences in thermal expansion between the glass master and the electroformed parts. This is necessary so that the reflective-face skin will remain in place during its formation, through removal from the plating tank, and during the stages of secondary preparation for attachment of the rigidizing members. Stresses must be accurately controlled and special provisions made to prevent leakage or entrance of the plating solution between the reflective face and the master during subsequent plating operations. Anode positioning, agitation techniques, and control of the various parameters associated with the electroforming process itself, are required in addition to the special tooling necessary to produce these configurations.

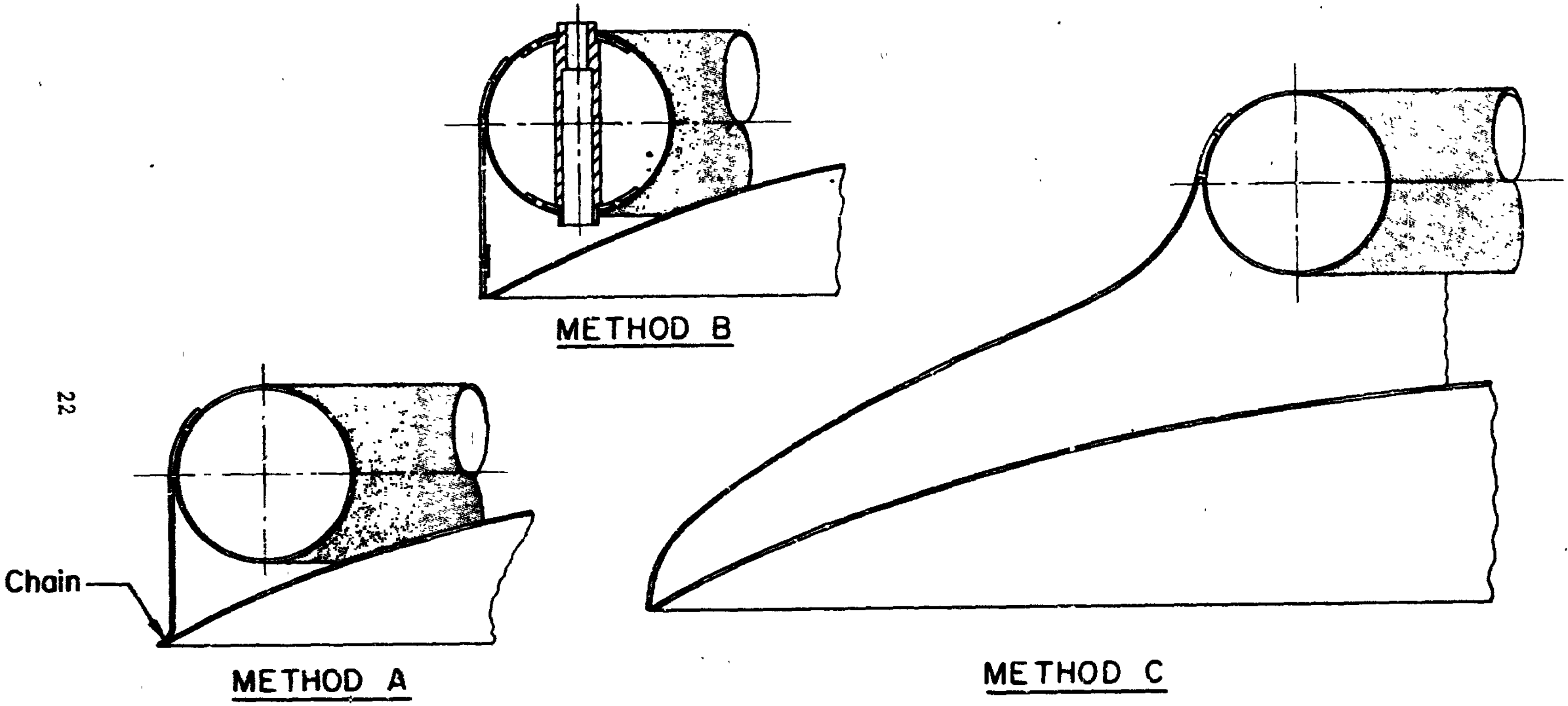


FIG. 2-1 ATTACHMENT METHODS - REAR TORUS RIGIDIZED MIRROR

Figure 2-2 shows an 18-inch diameter mirror skin with chain attached and illustrates one of the methods with which secondary attachment of the rear-mounted torus can be achieved. Figure 2-3 is a close-up of the chain lock showing in detail the method of obtaining encapsulation or lock-on of the secondary parts. Figure 2-4 shows a close-up of the torus attachment method.

Although the encapsulation method using the chain or wire locking techniques provides very strong mechanical attachment for secondary structures, certain problems exist relative to the application of this technique, particularly for larger concentrators. The chain or locking device must be in contact with the master at all points or the electroformed bond may not be structurally sound. Agitation is sometimes difficult and stress concentrations result due to the high current density conditions that exist at this point. An alternative to this lock-on on the back of the mirror skin itself is the formation at the outer edge of the reflective skin of a reverse-rolled edge or rim. In this technique an edge form is attached to the master and provides a master extension so that the formation of the reflective skin results in a rim extending to the rear of the mirror. Preparation of the master for this edge-bond method is shown in Fig. 2-5. This configuration is particularly desirable since, due to the tooling required, a seal is formed at the edge of the reflective skin that prevents entrance of plating solution during subsequent operations.

After formation of the skin the torus is positioned to the rear of the mirror and necessary filleting or auxiliary mandrels are prepared for subsequent growth of the structural element that will lock the torus to the reflective skin. Preparation of the small-scale sample for attachment of the torus is shown in Fig. 2-6. In the experimental studies this second technique, that of providing an edge band on the reflective face so that all attachments can be made on areas not affecting the figure or surface of the mirror, appears most successful. Figure 2-7 shows an 18-inch diameter mirror rigidized

FIG. 2-2 18-INCH DIAMETER MIRROR SKIN WITH CHAIN ATTACHED

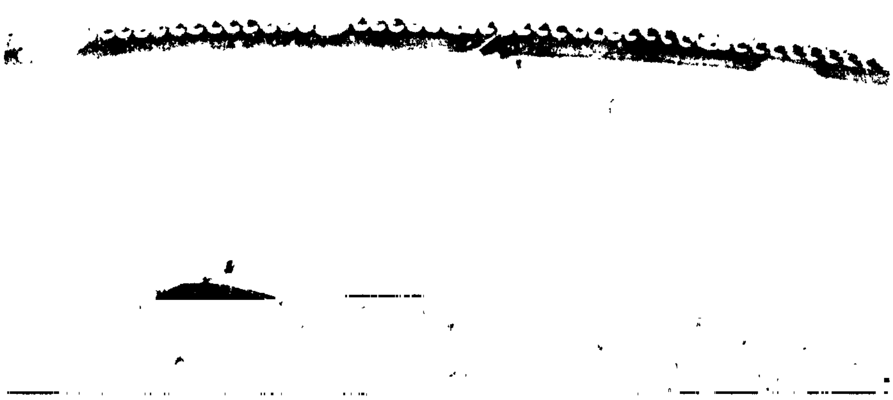


FIG. 2-3 CLOSE UP OF CHAIN LOCK DETAIL

FIG. 2-4
CLOSE UP OF TORUS ATTACHMENT

FIG. 2-5 PREPARATION OF MASTER FOR EDGE BAND METHOD

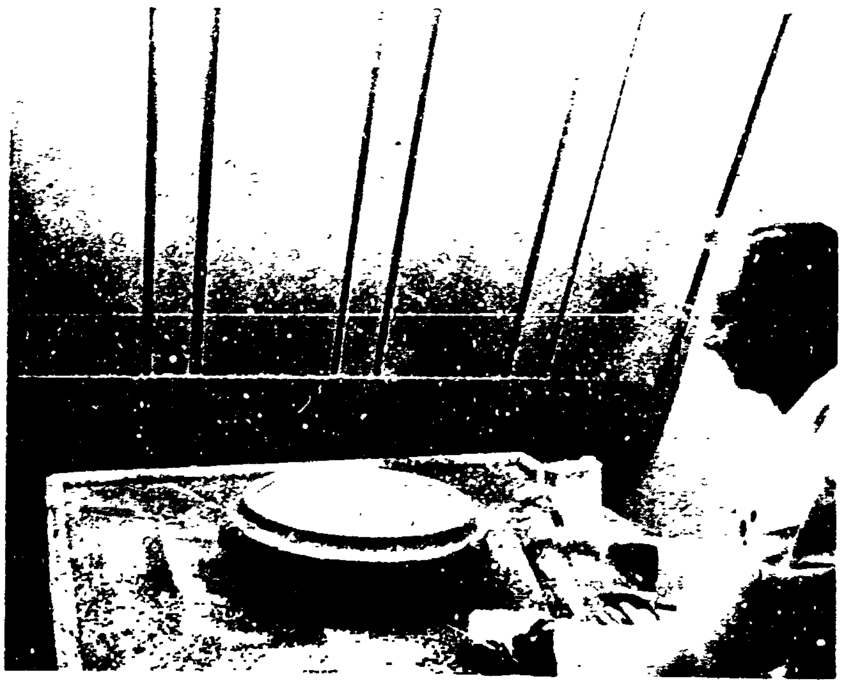


FIG. 2-6 PREPARATION FOR ATTACHMENT OF TORUS

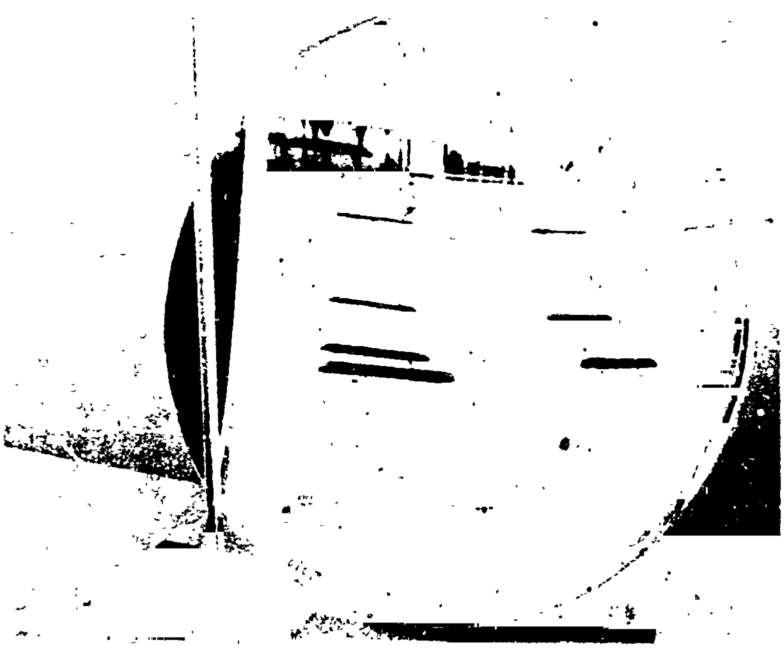


FIG. 2-7 18-INCH DIAMETER MIRROR RIGIDIZED WITH REAR MOUNTED TORUS SHOWING LACK OF EDGE ROLL with rear-mounted torus in which the lack of edge roll is evident from the reflected images in the picture. The staining that is evident around the edge of the mirror has been corrected as of this time and a number of test skins have been produced in which no leakage occurred and a structurally sound edge band was achieved.

2.3.4 Effects of Plating Stresses

The present knowledge of the electroforming processes and controls that are available make it possible to accurately control many of the various parameters during the formation of the required reflective-face skins and additional structural elements. Plating stresses can be controlled to produce either tensile or compressive stress in the resultant electroforms and in some instances these effects can be used to advantage during the fabrication of the various components. It has been established experimentally that the highest accuracy of geometry of reflective-face skins is obtained when a zero-stress condition is achieved during plating. This results in a part that has no tendency to deviate from the geometry of the master; the zero-stress condition prevents leakage of solution between master and reflective skin. Such leakage often results in staining, blushing, or other degradation of the reflective surface if stresses are not carefully controlled. Unfortunately, when low or zero stress is achieved during the formation of the reflective skin, parting from the master is more difficult since there is no tendency of the mirror skin to part itself due to internal stress conditions. For highly accurate concentrators, however, it appears imperative that zero-stress conditions be achieved during the formation of the reflective face itself.

Tensile or compressive stresses are intentionally used in some instances where joining or attachment encapsulation can be improved by their use. When forming internal-electroformed rivets for instance, low-current-density conditions that exist within the hole in the mandrel, or part, produce a characteristic that expands the electroformed rivet material in the hole, tighening the lock to a greater degree than could be achieved by other conditions. When encapsulating a torus, or part, from the outside, tensile stresses in the electroformed deposit can increase the encapsulation bond beyond the level that could be achieved through zero-stress plating.

If small heat-transfer or thermal-conductivity variations are expected in different portions of a structure, some compensation can be achieved during formation of the various parts by balancing the resultant thermal stresses against the inherent or plated-in stresses.

It is of utmost importance that new design concepts utilize the various conditions that can be achieved through the use of controlled electroforming techniques. Present knowledge of the controls possible, has provided a basis for certain design concepts and it is evident that as more knowledge is gained maximum advantage can be taken to produce concentrators of the lowest possible specific weight consistent with design or environmental requirements.

2.4 Development of 5-Foot Diameter Concentrators

A number of preliminary studies have been carried out prior to actual development of the 5-foot diameter concentrators. Improvement of plating techniques and controls of physical properties, which will be discussed in subsequent sections, are providing a basis for design and fabrication techniques for the 5-foot models that will materially aid in the ultimate construction of these units.

2.4.1 Preliminary Design Concept

Based on past information that was obtained from performance, shake and vibration testing, and small-scale studies conducted during the early portions of this program, a preliminary design concept for the 5-foot diameter concentrators has been developed. Prime factors considered involved simplicity, structural integrity, minimum weight, complexity of tooling and electroforming techniques, and a multitude of other factors. Figure 2-8 shows the preliminary design concept for the torus-rigidized 5-foot diameter concentrator that resulted.

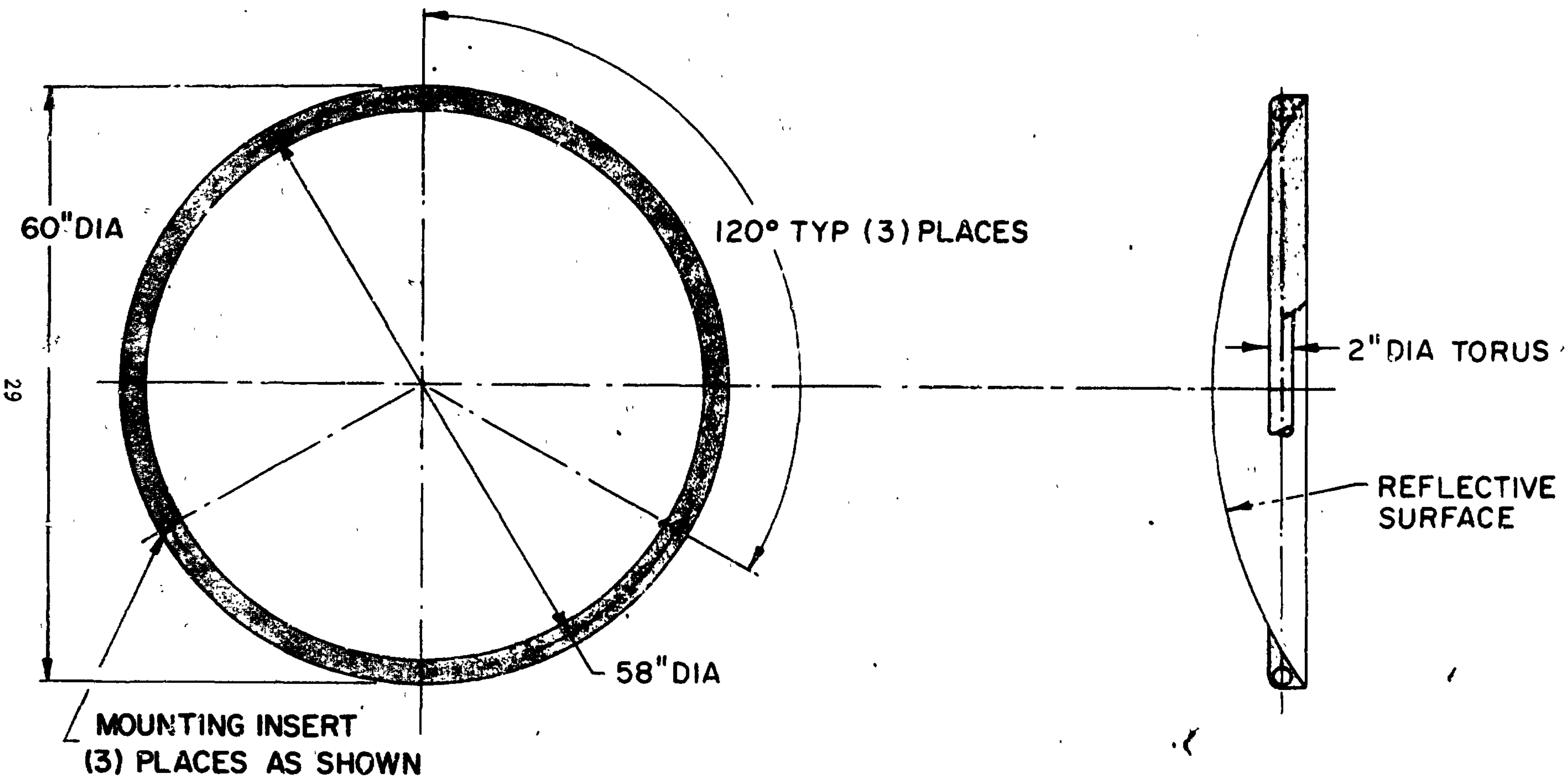


FIG. 2-8 TORUS RIGIDIZED 60-INCH DIAMETER LIGHTWEIGHT CONCENTRATOR

The all-electroformed torus will be attached to the rim of the reflective skin in a rear-mounted position by one of the methods previously described. The torus will have three mounting or support points spaced 120° or equidistant apart. Necessary rigidizing for the torus at points of attachment for mounting will be provided by electroformed-transition sections that will be incorporated as an integral part of the torus. These attachment points and transition sections are shown in Fig. 2-9. A lightweight, stainless steel, threaded sleeve is encapsulated by a "grow-in" technique in the torus-transition section that has a tapered wall thickness providing even distribution of loading from the points of attachment to the torus itself. An electroformed-continuous torus will then be grown over the transition sections while they are accurately positioned on an alignment and rotation fixture. This concept should produce a torus section considerably lighter than those previously achieved for 60-inch diameter concentrators.

2.4.2 Special Tooling

It was determined during prior programs that certain special tooling and fixtures were required to produce some of the components of the larger size concentrators in a practical and uniform manner. Earlier shake and vibration tests, accompanied by sectioning and measurement of the reflective concentrator face skins, showed that uniformity and control of face skin thickness was extremely important for structural stability. Small-scale studies showed that the required uniformity and control of thickness could be achieved by rotating the master in relation to the anodes during formation of the reflective skin. The process of rotation also provides other desirable effects. Agitation is improved in a uniform manner over the skin surface. When the part is mounted horizontally, with the mirror surface of the master facing downward, the resultant part is entirely free from inclusions that result when the part is formed face up in a stationary position.

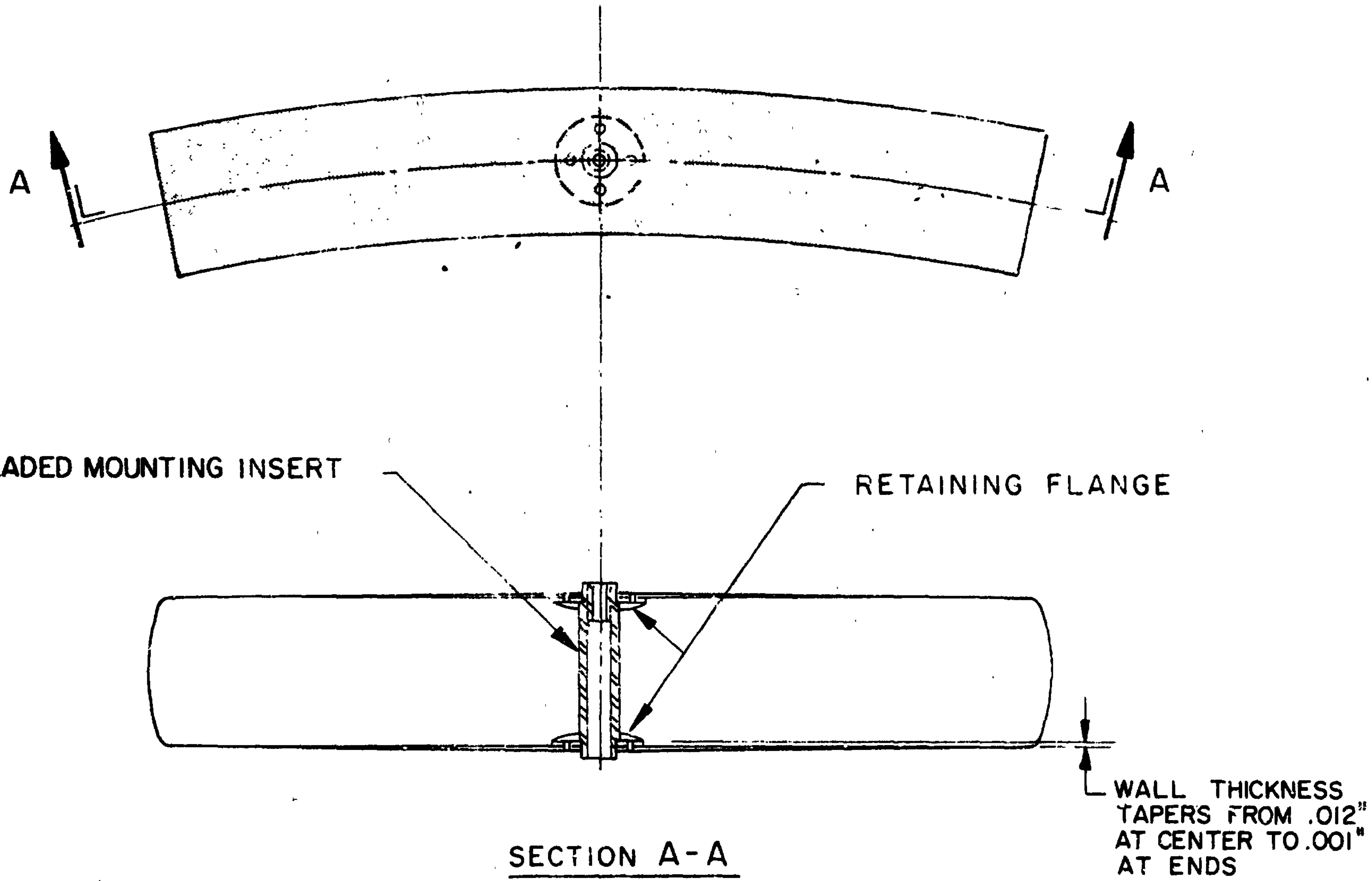
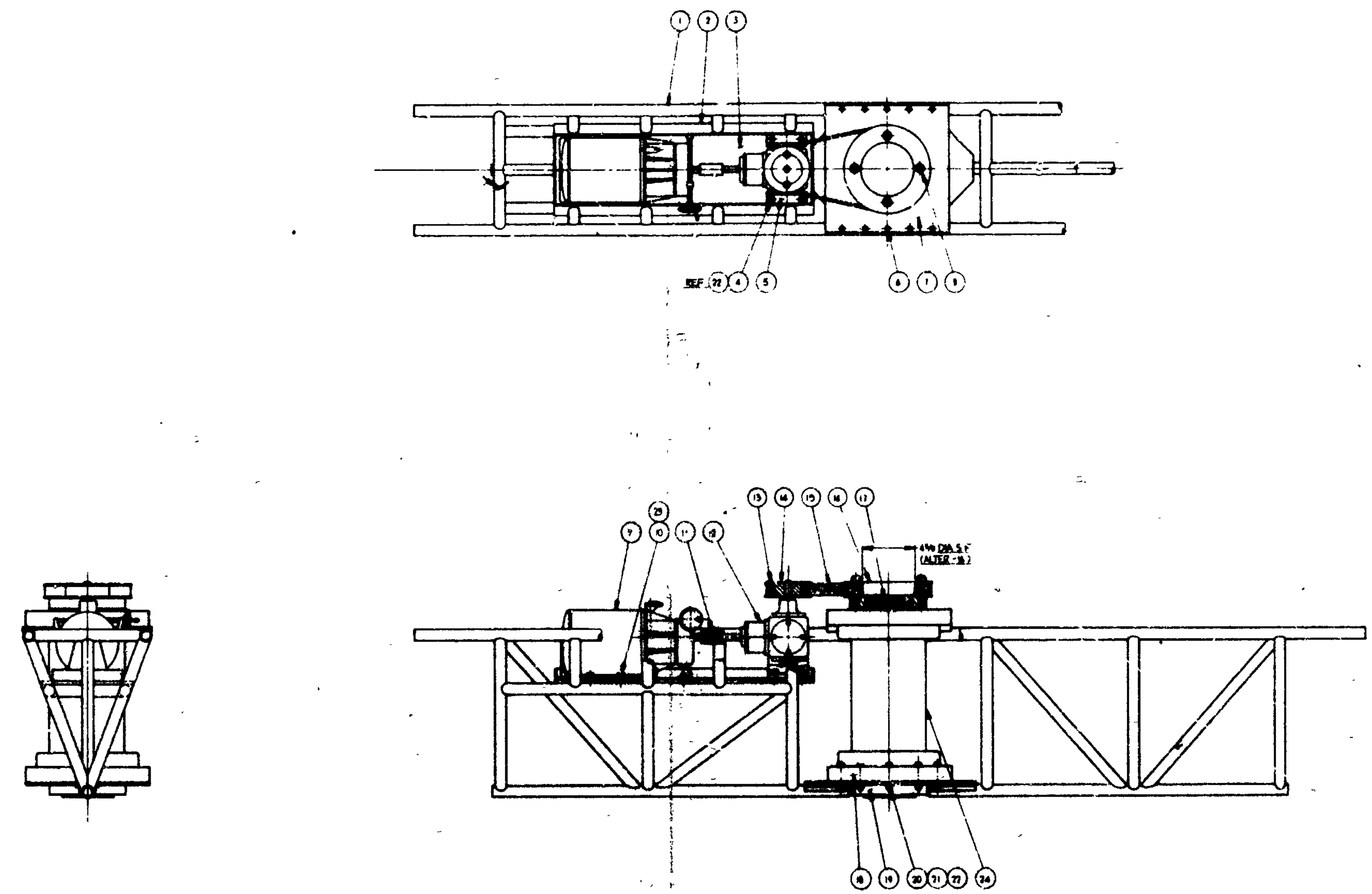


FIG. 2-9 ELECTROFORMED MOUNTING SEGMENT

Because of the relatively large bulk and weight of the 5-foot diameter master and related equipment, new rotational equipment had to be designed and fabricated. Basic designs for this rotating equipment are shown in Figs. 2-10 through 2-14. Figure 2-10 shows the main rotational assembly that includes the central spindle made in a tubular fashion so that, if necessary, plating solution can be pumped through the spindle during operation to provide additional agitation at points where required. The commutator assembly (including slip rings, brushes, etc.) is provided as a separate unit underneath the spindle assembly. This unit provides two isolated circuits so that, in addition to supplying cathode power to the master, auxiliary anodes can be placed where required on the rotating assembly and powered by means of this contactor. For copper plating where high current is required the two slip rings and brush assemblies can be run in parallel, providing current-carrying capacities over 2000 amperes. A master-holding fixture attaches directly to the lower flange of the commutator assembly. Figure 2-11 shows a detail of the rotator and spindle housing assembly. Figure 2-12 shows the support assembly for the rotating fixture that is essentially a truss section on which is mounted a reversible motor and speed reduction unit. Figure 2-13 shows the support fixture extensions that are used to adapt the unit to the 12- by 12-foot plating tank, which would be necessary if masters larger than 5 feet in diameter were to be rotated. Figure 2-14 shows the complete assembly.

An additional piece of tooling and special equipment that was designed and fabricated is a swivel fixture, or mirror handling support. Problems have been experienced in the past relative to supporting or holding the master or finished concentrator in the various positions required for processing or fabrication in such a manner that possibilities of damage would be minimized. This fixture is capable of handling and holding the master or mirror in all positions from horizontal to vertical (or slightly past vertical for cleaning operations). The center shaft is mounted in a bearing so that the part can



1	24	REF SHOP SKETCH	ROTATER HOUSING			
5	23		SPLIT LOCK WASHER			
14	22		SPLIT LOCK WASHER	¼-20 NOM	STEEL	
10	21		STD HEX NUT	¼-20	STEEL	
10	20		HEX HEAD BOLT	¼-20 X 1	STEEL	
1	19	REF SHOP SKETCH	ADAPTER FLANGE			
1	18	185-11146-2	SUPPORT PLATE			
	17	185-11135	SHAFT - ROTATER			
1	16	CAT No 48H100	PULLEY - GILMER			
	15	CAT No XOH100	BELT - GILMER			
1	14	CAT No 2.202-A	BUSHING - GILMER			
1	13	CAT No 22H100	PULLEY - GILMER			
1	12	CAT No L2	SPIRAL GEAR UNIT - BOSTON			
1	11		COUPLING (TO SUIT)			

185-11150

5	10		HEX HEAD BOLT	5/16-18 X 5/8	STEEL	
1	9	CAT No 10E5A9	ZERO-MAX WITH GEARHEAD & MOTOR			
4	8		SOC HD CAP SCR	¼-13 X 1½		
1	7	185-11146-1	SUPPORT PLATE			
10	6		SOC HD CAP SCR	¼-20 X ¾		
2	5	185-11153	BRACKET MNT G			
4	4		HEX HEAD BOLT	¼-20 X ¾	STEEL	
1	3	185-11155	OIL PAN			
1	2	185-11154	PLATE - MOUNTING			
1	1	185-11139	SUPPORT ASS'Y - ROTATING FIXTURE			

LIST OF MATERIALS

UNLESS OTHERWISE NOTED

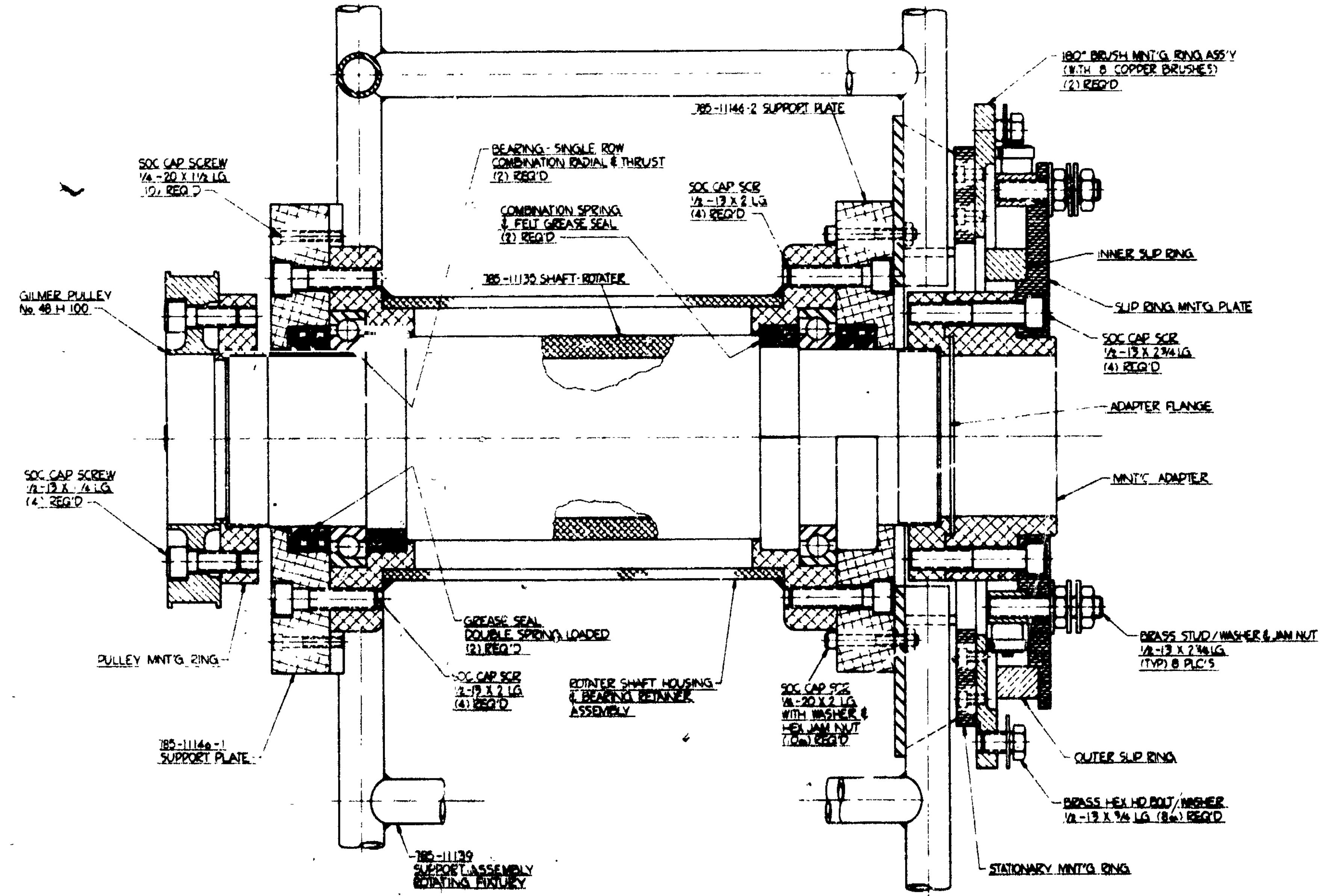
ELECTRO-OPTICAL SYSTEMS, INC.

ROTATING FIXTURE ASSEMBLY

185-11150

FIG 2-10 ROTATING FIXTURE ASSEMBLY

2100-1R-1



2100-IR-1

FIG. 2-11 ROTATOR HOUSING ASSEMBLY

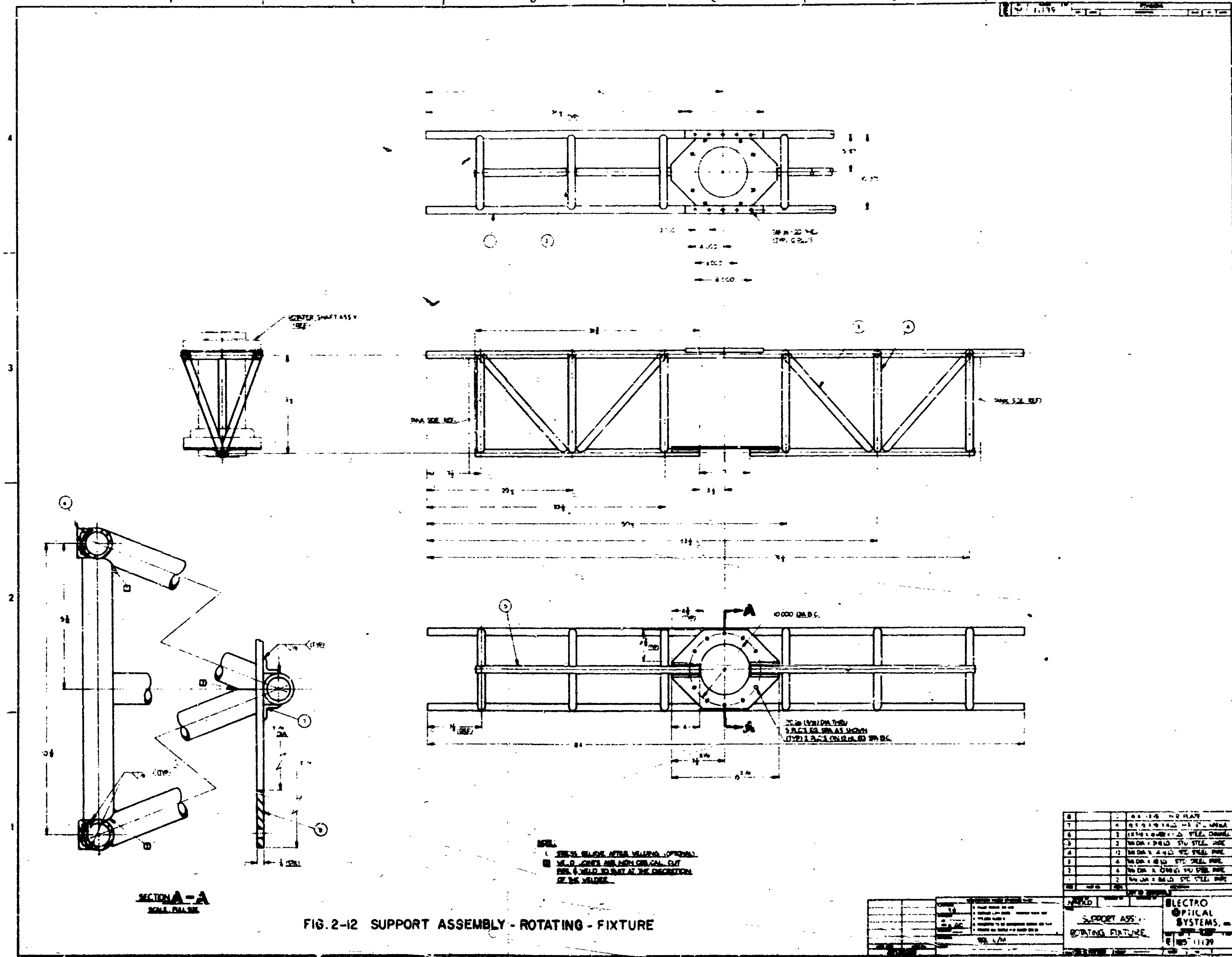
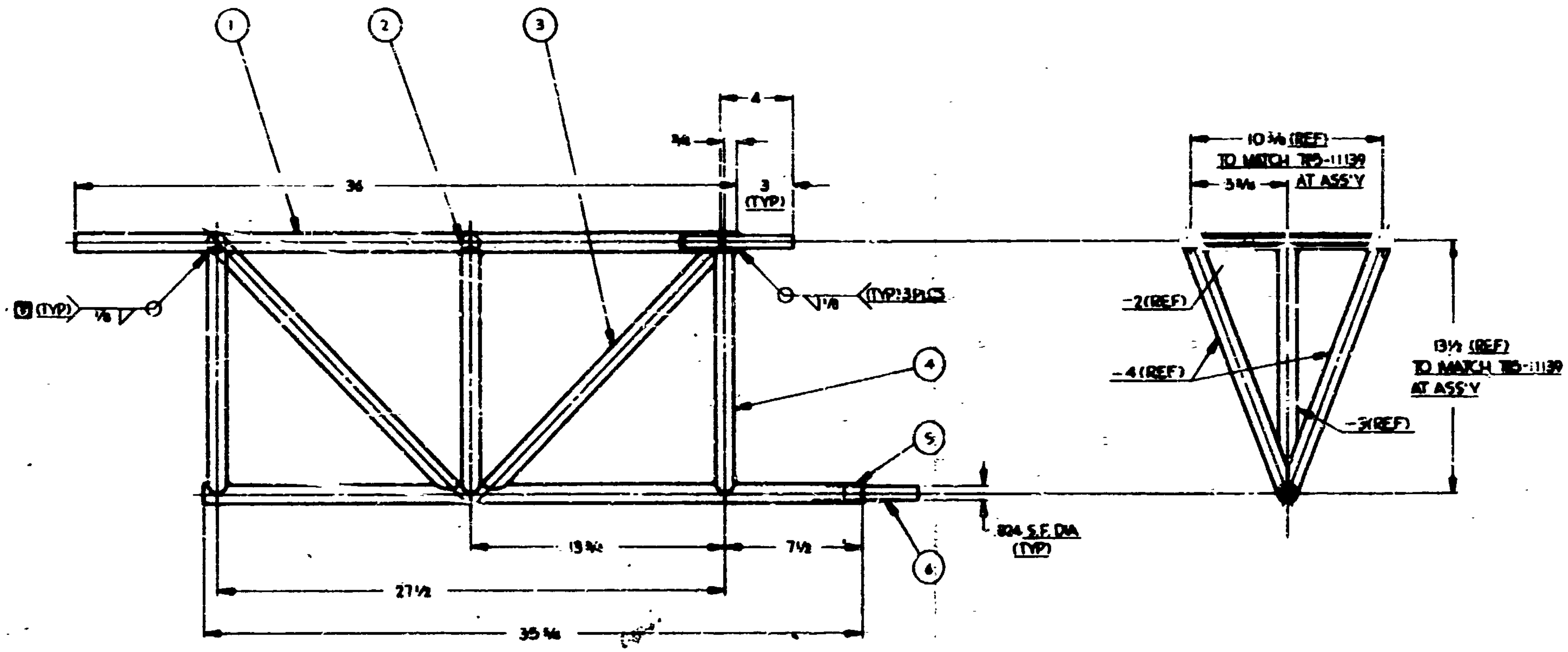


FIG. 2-12 SUPPORT ASSEMBLY - ROTATING - FIXTURE

2100-IR-1



785-47

3	6		DOWEL	1/2 DIA X 4 LG	1/2 DIA STD STL PIPE	
:	5		BRACE	3/4 DIA X 35 3/4	3/4 DIA STD STL PIPE	
6	4		SUPPORT	3/4 DIA X 14 1/2		
2	3		GUSSET	3/4 DIA X 18 1/2		
3	2		CROSS ARM	3/4 DIA X 0 3/8		
2	1		BAR	3/4 DIA X 36.5	3/4 DIA STD STL PIPE	

LIST OF MATERIALS

9. TORCH CUT JOINTS TO SUIT & LOCATE AS SHOWN.
8. PERMANENTLY IDENTIFY WITH PART NO. ELECTRIC PENCIL ☐ METAL STAMP ☐ TAG ☐ . 1/8 HIGH NUMERALS.
7. 45° CHAMFER TO ROOT DIA. ON ALL SCREW THREAD ENDS.
6. THREADS PER MIL-7742, CLASS 2.
5. FILLET RADIUS ___ MAX.
4. SURFACE ROUGHNESS 125 MAX.
3. DIAMETERS TO BE CONCENTRIC WITHIN ___ T.I.R.
2. ON WELDMENTS REMOVE ALL LOOSE SCALE AND WELD SPLATTER.
1. REMOVE ALL BURRS AND SHARP EDGES.

NOTES: UNLESS OTHERWISE SPECIFIED

FIG. 2-13 SUPPORT FIXTURE EXTENSION

UNLESS OTHERWISE NOTED

ARNOLD

ELECTRO-OPTICAL SYSTEMS, INC.
Pasadena, California · MUrray 1-4871, SYcamore 3-0891

SUPPORT FIXTURE EXTENSION

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SHEET 1 OF 1

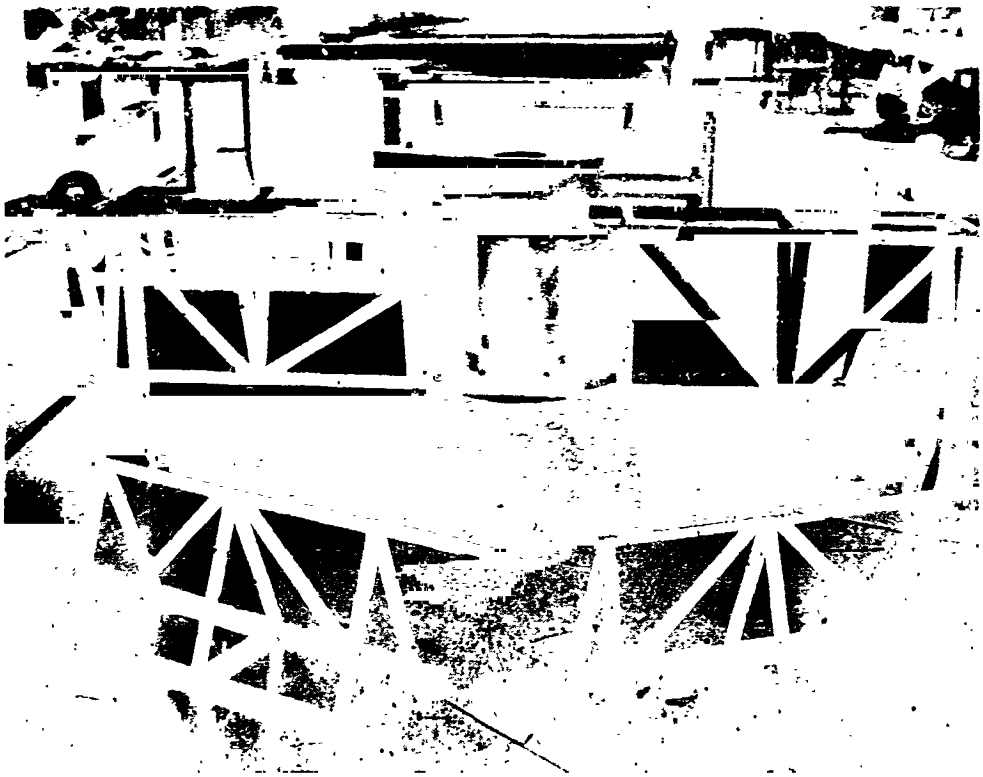

FIG. 2-14 ROTATOR ASSEMBLY AND EXTENSIONS

be rotated to, and locked in, any position. The design incorporates a motor drive for subsequent cleaning operations where controlled speed of rotation may be required. The present unit, however, has been fabricated without the motor drive. If rotation is required for wax removal or other cleaning processes, the power unit may be added at a later date. Figure 2-15 shows the basic swivel fixture and assembly. Figure 2-16 shows the completed handling fixture positioned for holding the concentrator in a horizontal position. Figure 2-17 shows the fixture extended for holding concentrators in the vertical position. This fixture is capable of holding and handling mirrors up to 10 feet in diameter.

A considerable number of additional fixtures and special devices are required during the various stages of preparation for electroforming the 5-foot diameter concentrators, using rotational techniques. Since the design and applications of these new techniques are still in the preliminary stage, detailed designs have not been made. Each required item will be developed and fabricated as the 5-foot diameter mirror development continues, and those units that become standard will be documented when they have reached their final design concept. Because of the peripheral back-mounted torus design that was chosen, no extensive or involved master configuration is anticipated.

2.4.3 Fabrication of Preliminary Models

Fabrication has been started on the 5-foot diameter models. The initial units will use the rim-band technique, and rear-mounted torus. The first of the electroformed mounting segments or transitional-torus sections has been completed and is shown in Fig. 2-18. This unit appears to be entirely successful and fabrication is continuing on the remaining units required for the concentrators to be produced during the course of the program. Tooling has been modified to produce the wax mandrel required to form the rim on the 5-foot diameter reflective-face skin. The preliminary model will be plated using an aluminum tube torus in order to evaluate the techniques used for forming and plating

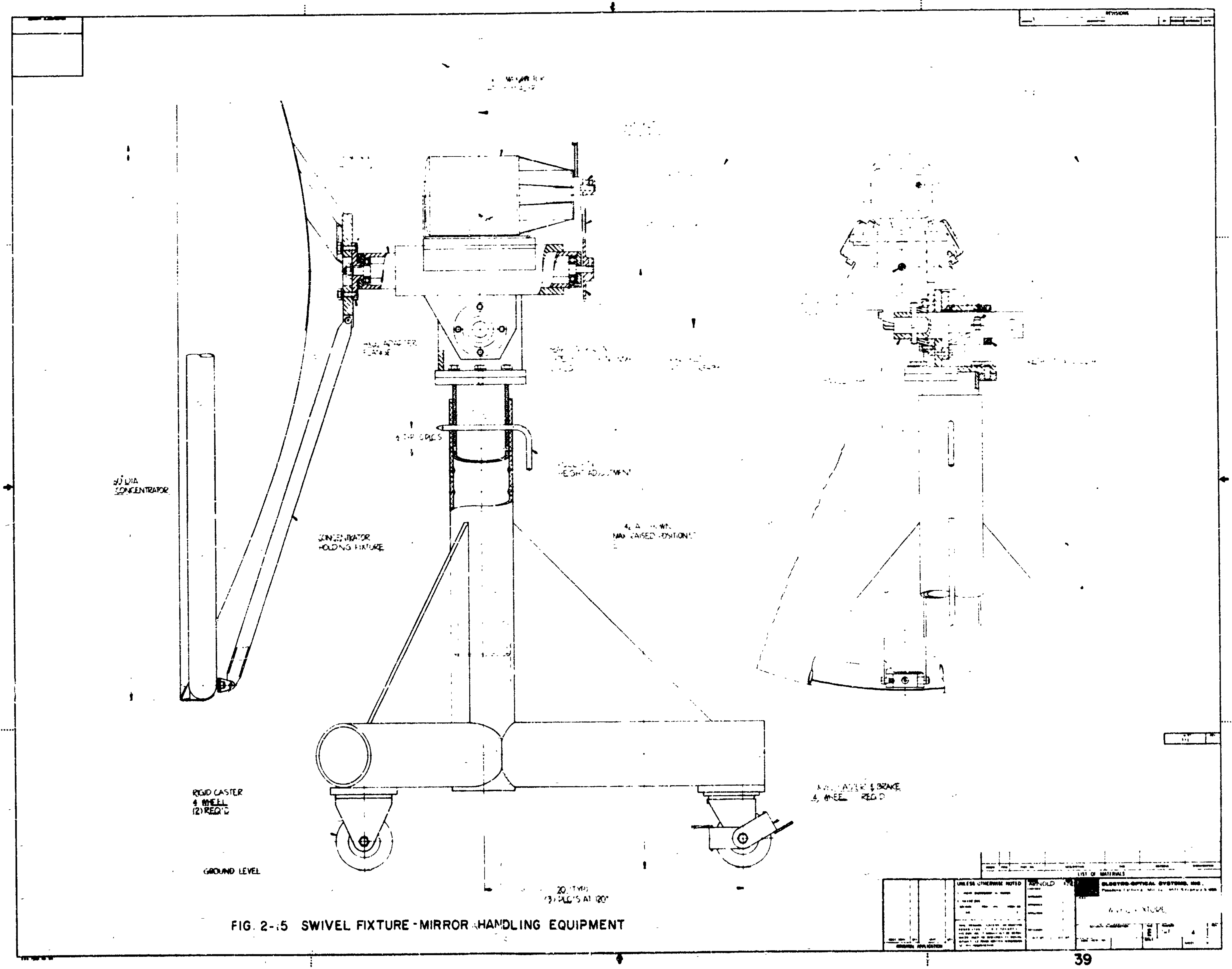

FIG. 2-15 SWIVEL FIXTURE - MIRROR HANDLING EQUIPMENT

2100-IR-1

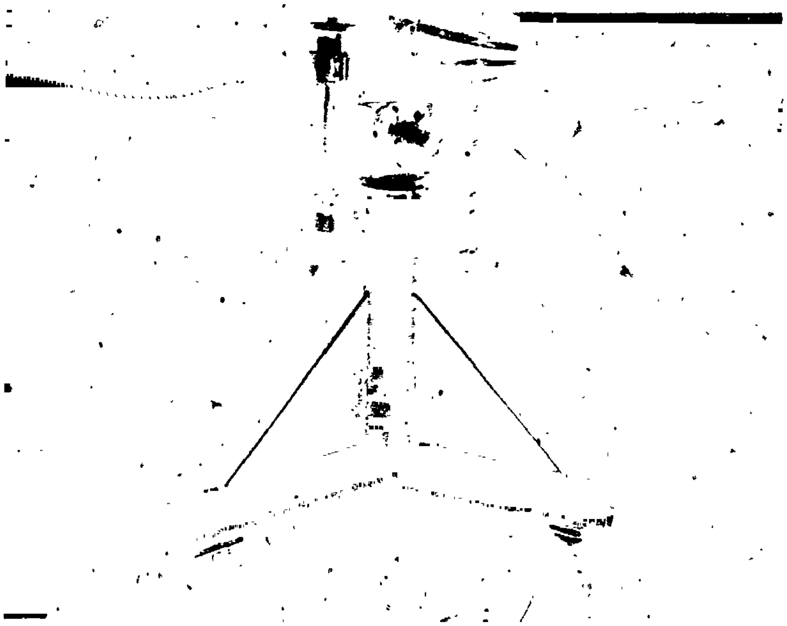

FIG. 2-16 MIRROR HANDLING FIXTURE - HORIZONTAL MIRROR POSITION

FIG. 2-17
MIRROR HANDLING FIXTURE - VERTICAL MIRROR POSITION

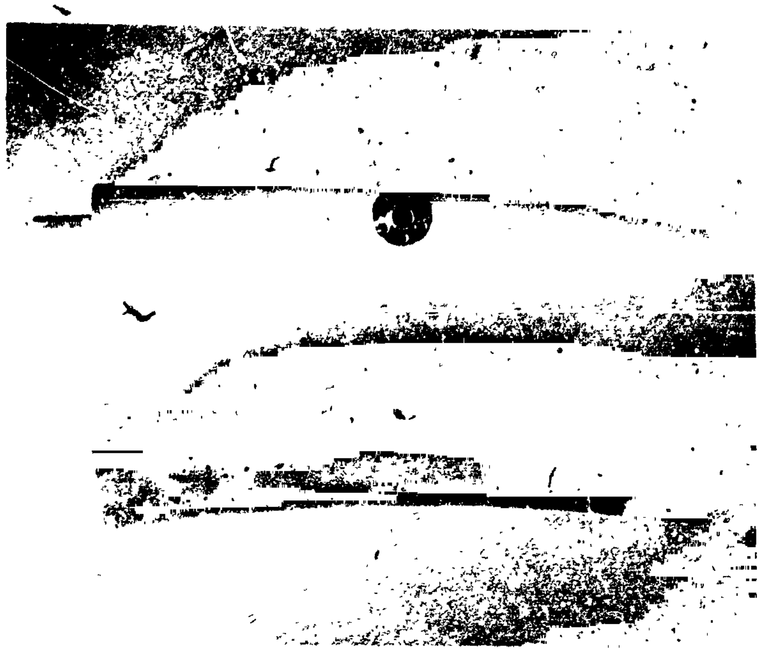

FIG. 2-18 ELECTROFORMED TORUS MOUNTING SECTIONS

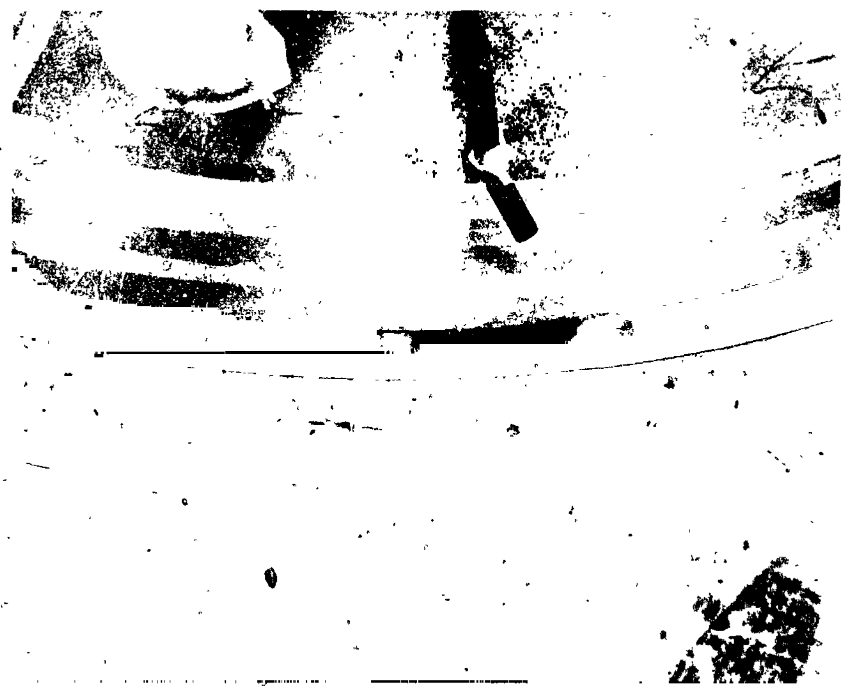

FIG. 2-19 RIM TOOLING FOR 60-INCH DIAMETER TORUS ATTACHMENT

the reflective skin, and for the attachment of the structural section between the reflective skin and torus itself. Subsequent units will include all-electroformed torus sections. Figure 2-19 shows a portion of the tooling required for the fabrication of a 5-foot diameter mirror skin with integral edge band. Power is transmitted to the rim of the master by means of a clamp ring to which cathode power is uniformly distributed. Figure 2-20 shows the preliminary plating fixture that is being used for evaluation of the techniques employed for forming the reflective skin. Subsequent units will employ the rotational fixture and related equipment that is in the final stages of fabrication.

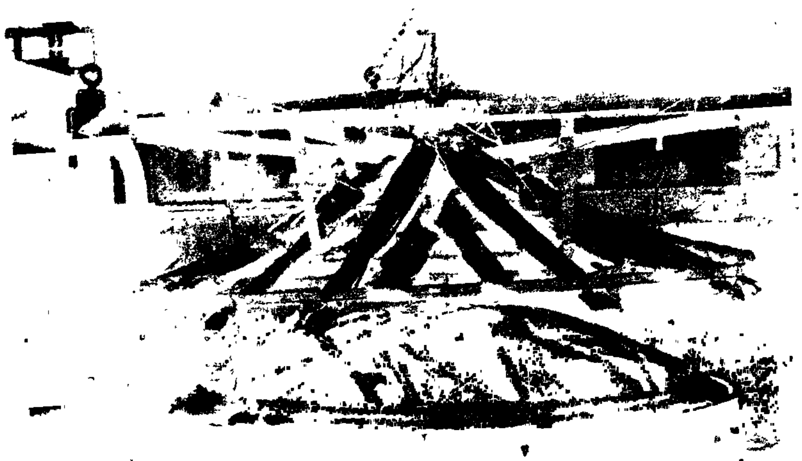

FIG. 2-20 60-INCH DIAMETER PLATING FIXTURE FOR EXPERIMENTAL REAR MOUNTED TORUS

3. DEVELOPMENT OF PLATING TECHNIQUES

A key factor in the successful fabrication of efficient concentrators employing electroforming techniques is complete understanding of, and the ability to control the various parameters associated with the electroforming process.

3.1 Small-Scale Studies

Small-scale plating studies were initiated at the beginning of the program and will be continued throughout the remaining period to enable maximum information to be obtained relative to the various parameters affecting or controlling the electroforming processes. In order to isolate this more basic research from the applied plating techniques, a separate clean room and analytical laboratory was established adjacent to the production plating operation. Figure 3-1 shows a portion of this research plating and analysis laboratory.

3.1.1 Solution Analysis and Controls

In addition to the techniques previously reported, more detailed analyses procedures have been established and the plating solutions constantly monitored to provide greater control over the resultant electroformed parts. Development of hard copper and other experimental solutions is still in the preliminary stage and neither standards or basic controls have been established for these solutions as yet. Nickel-electroforming techniques and related parameters and bath requirements are more firmly established. Definite procedures have been set forth and the experimental baths are analyzed on a regular basis. In addition to stress tests, which are regularly made at varying bath temperatures, analyses are made for trivalent chromium, sulfate, boric acid, chloride, and total-nickel content. Variations in these techniques have produced periodic changes in the method of analysis, which has in turn resulted in a greater degree of accuracy and reduction in required analyses time. It is felt that this is an important factor since, prior to and during the formation of structural parts by the electroforming process, a high degree

FIG. 3-1 PLATING RESEARCH AND ANALYSIS LABORATORY

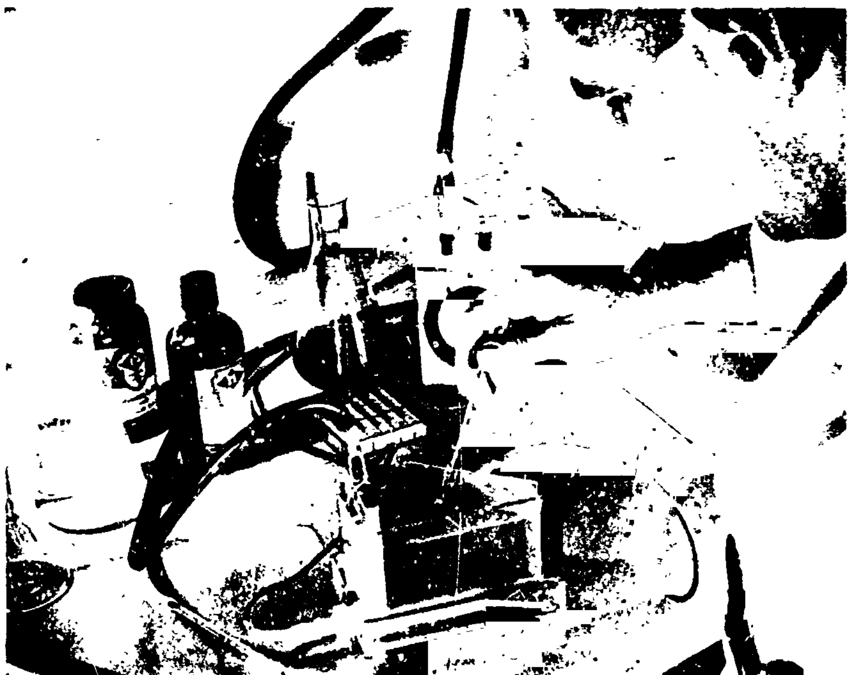

FIG. 3-2 HULL CELL TESTING

of control over the bath conditions is required if stress levels and physical properties are to be closely controlled. Details of these analytical processes will not be included until the final report at which time, it is felt, all modifications will be completed and the processes will be uniform and of a standard nature.

In addition to analyses for solution composition and stress determination, Hull cell testing has been employed to spot check the various solution compositions. With this device, cathode and anode are mounted at an angle to one another in a fixed volume of solution. During plating on the cathode, a complete range of current densities is produced due to the physical relationships of anode and cathode. Visual observations can then be made of the surface condition and quality of plating that results from the variations from high to low-current density. The quality of the resultant electroform, grain structure, appearance, etc., can be rapidly analyzed in this manner. Figure 3-2 shows the Hull cell test device. Figure 3-3 shows some of the additional monitoring and control equipment that has been incorporated in the analytical lab. This equipment includes devices for periodic reversal of current during plating, and detailed recording of plating time in ampere hours or ampere minutes. Both current and voltage are recorded on strip-chart recorders to aid in the evaluation of certain effects such as changes in additive agent due to plating conditions and decay rate of additives.

3.1.2 Stress Determination and Control

In that determination and control of stress in electroforms is of prime interest for solar concentrator fabrication, continued emphasis has been placed on determination of stress. A number of devices have been employed for stress measurement, including the Spiral Contractometer, which was described in earlier reports, and various strip-testing methods have also been employed.

Strip-testing techniques continue to be the most versital methods for day-to-day evaluation of the various conditions. Modifications to this technique have involved the use of various masking

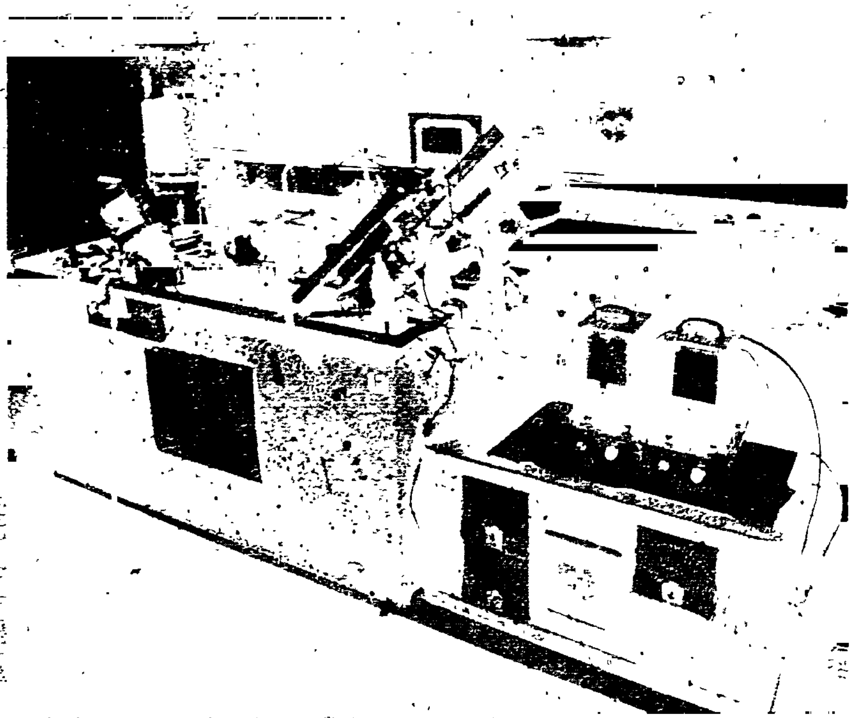

FIG. 3-3 MONITORING AND CONTROL EQUIPMENT

FIG. 3-4 MODIFIED STRIP TEST FIXTURE

techniques in conjunction with the strip test in an effort to balance current density to produce more uniform test characteristics over the surface of stress-test strip itself. A definite reduction in current density, and therefore stress characteristics, has been achieved over the edges and corners using this new configuration. Only slight differences were noticed in test-strip reflection when tests were made under identical conditions using the old and new configurations. Either method appears to offer a reproducible means of making direct comparisons between various plating conditions. The modified strip-test fixture is shown in Fig. 3-4.

A more sophisticated device for the determination of stress has recently been devised and Electro-Optical Systems has obtained one of these units for comparison to other stress measuring devices. This unit, known as a stressometer, is shown in Fig. 3-5. With this device a thin metal diaphram is used as the end closure for a shallow plastic cylinder. The diaphragm becomes the cathode of the test circuit and a conforming anode is used and positioned directly above the cathode diaphram. The cavity behind the diaphram contains a fluid that is connected to a small capillary tube. The unit must be carefully calibrated and temperatures maintained very accurately. Because the unit is sensitive to both temperature and pressure fluctuations, as well as to stresses occurring on the test cathode, its use is rather involved. If these outside factors are carefully controlled, however, the instrument is capable of measuring a very small amount of stress occurring in the material that is being electrodeposited on the diaphram (cathode). Since its calibration and use is so involved, it is not practical as a working tool, but is valuable for determination of near-zero stress conditions.

All of the stress-measuring devices are acceptable for use in the solutions with which this program is concerned, and a large amount of information is being obtained on the various compositions and electroforming parameters for both copper and nickel electroforming solutions.

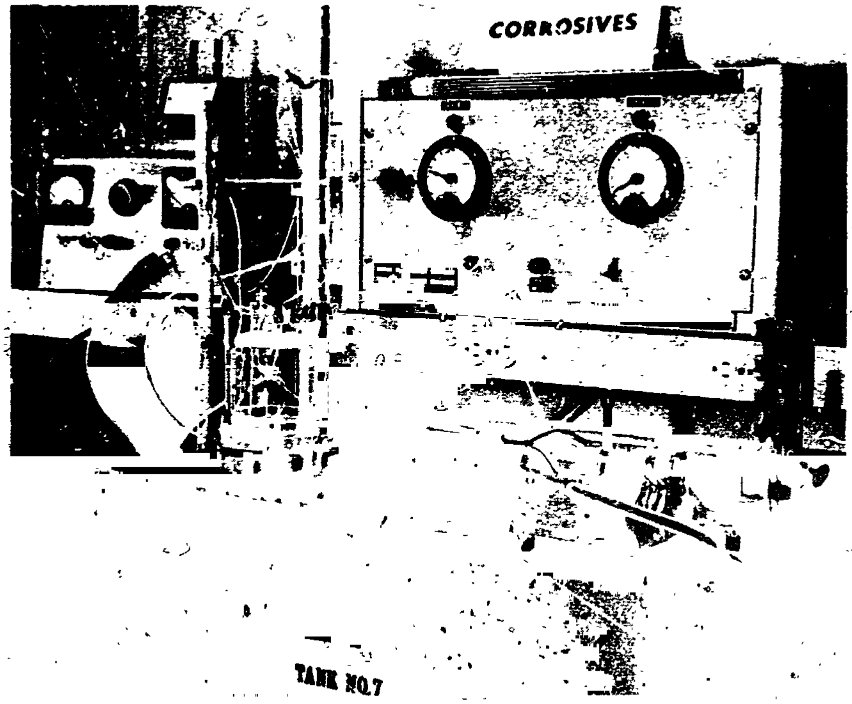

FIG. 3-5 STRESSOMETER

A typical stress versus current-density curve obtained with the strip-test technique at various temperatures is shown for a basic-nickel solution in Fig. 3-6. Stress versus current density for one of the more desirable modified copper solutions is shown in Fig. 3-7. Variations in current density are one of the key factors producing variations in stress in the resultant electroform. Additionally, current density or the distribution of current density over a typical part is one of the most difficult parameters to control. It is highly desirable to obtain a set of conditions where the stress-versus-current-density curve is flat so that wide fluctuations of current density over the various portions of the part will not result in appreciable variations in stress. This condition can be approached through the use of elevated bath temperatures. However, the use of elevated temperatures is often accompanied by other undesirable effects such as greater variations due to nonuniform thermal expansion of various components and other related factors. It can be seen from these graphs that for any given configuration, if the current density at that point is known, the stress that will result in the electroform can be determined. It is possible to adjust conditions to produce either compressive or tensile stress or, as is usually more desirable, near-zero stress conditions. The copper electroforming solution shown in Fig. 3-7 appears to hold promise of maintaining low or near-zero stress conditions over a wide range of current densities under certain temperature agitation conditions.

3.1.3 Chromium as a Surfacing Material

Chromium and other bright, hard deposits have been considered desirable as surfacing materials to provide protection to the reflective-face skin. A number of studies have been undertaken employing various bath compositions and plating techniques in an effort to produce a highly reflective, hard, durable surface condition. An effective chromium plating solution has been achieved that provides a highly reflective chromium overcoat.

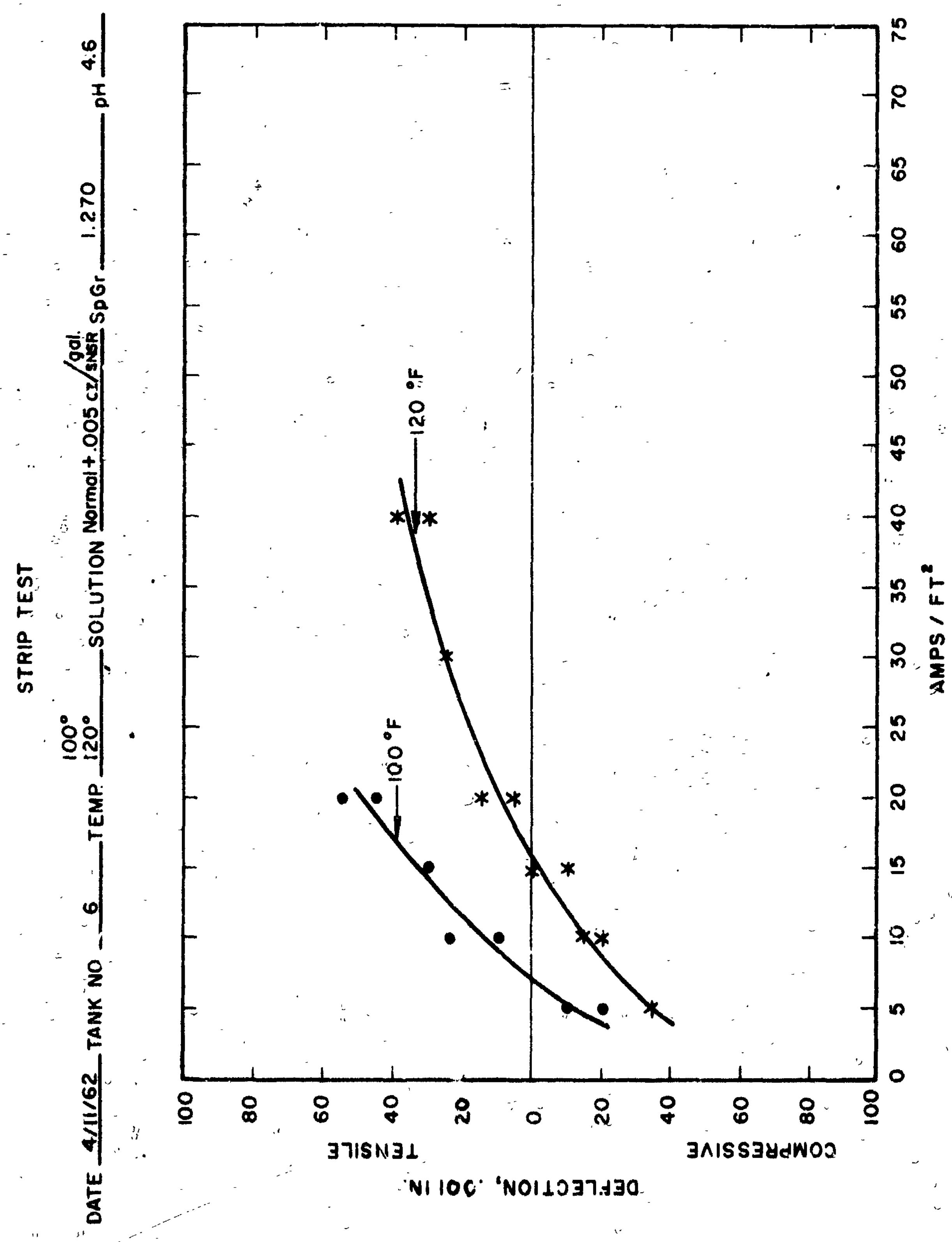

FIG. 3-6 STRESS VS CURRENT DENSITY FOR TYPICAL NICKEL SOLUTION

STRIP TEST

DATE 5/3/62 TANK NO. 7 TEMP 100°F 80°F SOLUTION Modified Acid Copper SpGr 1.206 pH 1

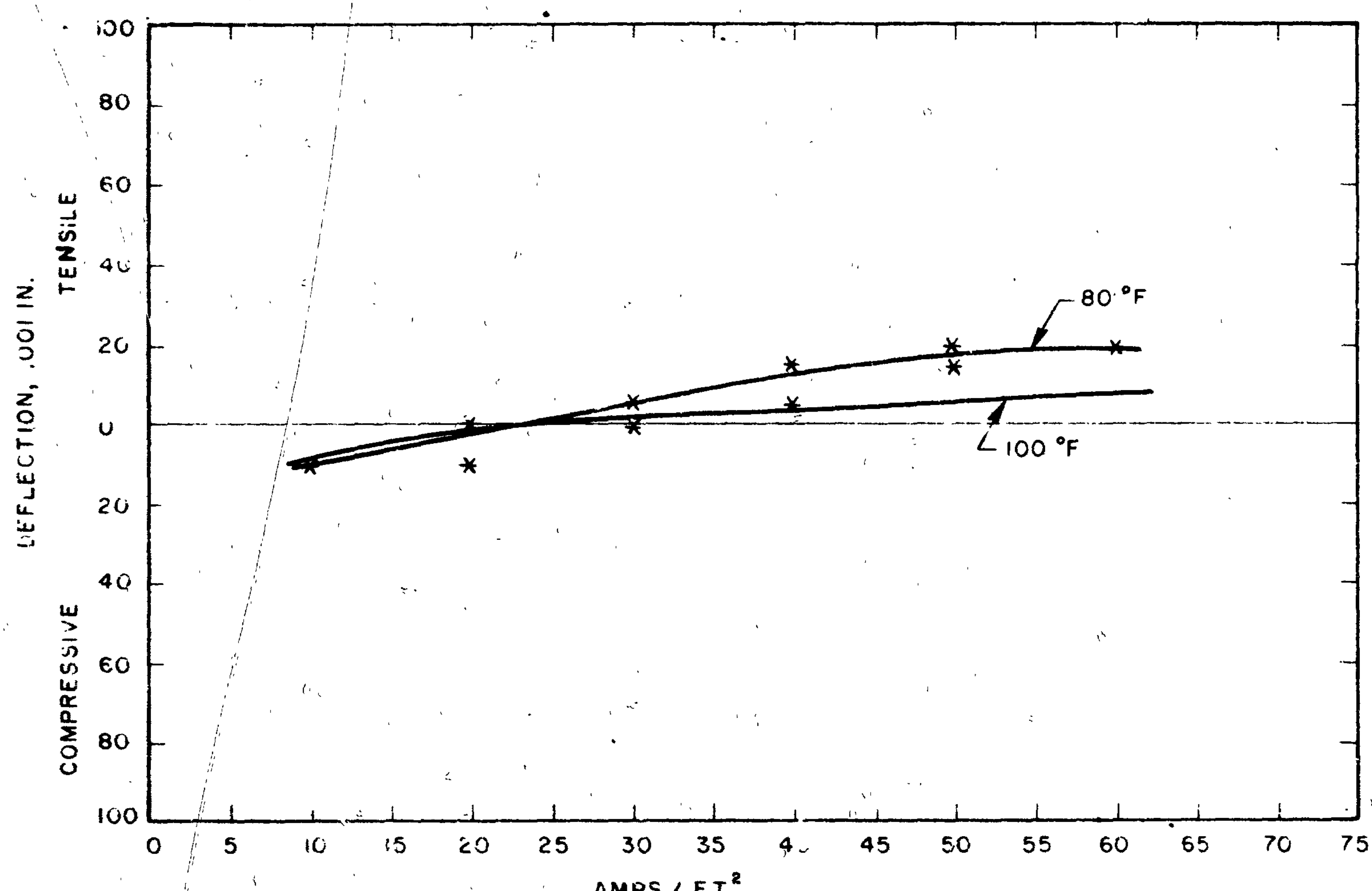

FIG. 3-7 STRESS VS CURRENT DENSITY FOR TYPICAL MODIFIED COPPER SOLUTION

Two methods were considered for the application of chromium:

1. Direct deposition of the chromium on the mirror master with subsequent electrodeposition of the structural material.
2. Electroforming of the reflective face in the usual manner with a secondary flash protective overcoating of chromium.

Little success has been achieved in the first instance. A number of electroformed nickel samples have been successfully overcoated with chromium, however. These samples have been tested together with electroformed nickel reflective surfaces that were overcoated with a flash of rhodium metal. These samples have been included with other reflectivity samples for testing and the results will be reported in a later section of this report. The appearance of the chromium and rhodium-plated parts is quite good visually, and the abrasive resistance appears to be excellent.

At first, considerable difficulty was experienced in determining the best range of current densities and general configurations to provide maximum brightness of the chromium or rhodium flash without the need for any subsequent polishing. It appears, however, that a reasonably broad range of conditions can be achieved that will permit plating to the necessary degree of brightness.

3.1.4 Monitoring of Solution Additives

The possibility of adding and monitoring the amount of solution additives required during the actual plating process has been considered. Insuffucient information has been gained, as of this time, relative to the various decay rates of the solution additives to enable a practical approach to this problem. Many of the additives are organic in nature and cannot be readily analyzed. It has been determined, however, that through analysis for the basic components, as previously described, and the continued use of strip testing to determine stress characteristics, the bath conditions can be readily determined. When deviations of stresses or solution content are observed, necessary additions can be made. Most of the structures with which this program is involved are relatively thin in nature and plating or electroforming is accomplished over a relatively short period of time. With the possible exception of the modified copper solution, which appears to change or decay quite rapidly, it is not expected that any additions or changes would have to be made during the course of plating. A more exact determination of these conditions as related to the modified copper solutions will be made during the remainder of the program.

3.2 Determination of Physical Properties of Electroformed Material

A wide variation in the appearance of grain structure, stiffness, brittleness, and other characteristics in the electroformed samples of various materials has been observed. In order to determine the variations in physical properties that exist for different electroformed materials, a series of tests has been outlined in which all of the possible parameters will be varied to make test specimens that will be subjected to the usual tests for tensile strength, percent elongation, yield, and molulus of elasticity. Hardness and other conditions will also be evaluated.

3.2.1 Variations in Physical Properties

A large number of test specimens has been produced for physical property measurements. The various parameters affecting or influencing the resultant electroforms have been varied independently, where possible, to determine their influence on the resultant structure. Test coupons were prepared by electroforming to approximately 0.010 inches or less in thickness, on a flat rectangular mandrel. In most instances a glass plate has been used for the mandrel but, to determine the effects of substrate if any, other materials have also been used. This same technique has been used to produce electroformed samples for the reflectivity tests. The geometry and relationship of anodes to cathode were balanced in such a way that the center of the test plate was uniform in thickness. The test coupons were then cut from the center of the test sheet in such a manner that three coupons were obtained from each panel. These were then machined to the dimensions required for testing, and supplied to the testing laboratory. Test coupons and reflectivity samples that were obtained from these electroformed tests panels are shown in Fig. 3-8.

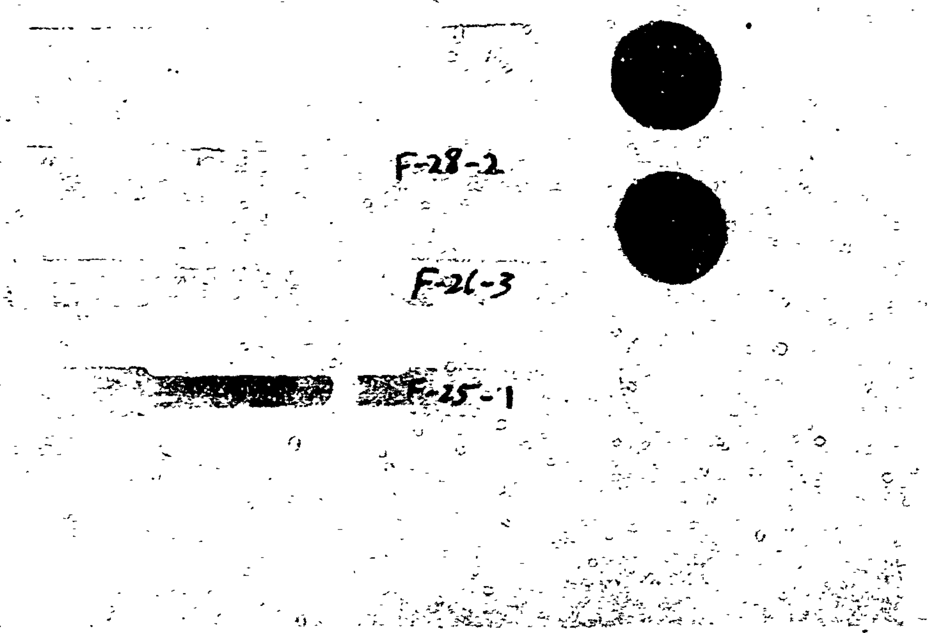

FIG. 3-8 ELECTROFORMED TEST COUPONS AND REFLECTIVITY SAMPLES

As previously stated, some parameters can be varied independently while others produce interrelated effects, or can only be varied in conjunction with other parameters. Initial tests involved a standard solution and controlled conditions of agitation, current density and geometry while bath temperature was varied. In other instances, agitation, current density, and other factors were independently varied while the remaining parameters were maintained in a constant condition. Conditions that have been evaluated to date are as follows:

Tensile tests were performed on samples plated in the Barrett sulfamate nickel solution. The pH, specific gravity, nickel content, boric acid and anti-pit agent were kept to the manufacturer's specifications. Specimens 11 x 16 inches were plated on plate glass sensitized with chemical silver or nickel sheet stock. From each specimen three samples were cut to ASTM physical test coupon size with a 2-inch gauge length. The parameters varied were temperature, current density, agitation and substrate. Two tanks were also compared.

The following chart will serve as a reference to the test data.

PHYSICAL TEST REFERENCE CHART

Sample No.	Temp. $^{\circ}F$	C.D. Amps/ft^2	Agitation Yes - No	Substrate Material	Thickness (mils)	Tank No.
1.			Temperature Change			
F-18	85	15	No	Glass	10	5
F-17	100	15	No	Glass	10	5
F-15	120	15	No	Glass	10	5
F-26	140	15	No	Glass	10	5
2.			Current Density Change at $100^{\circ}F$			
F-36	100	5	No	Glass	10	5
F-3	100	10	No	Glass	10	5
F-17	100	15	No	Glass	10	5
F-39	100	40	No	Glass	10	5

PHYSICAL TEST REFERENCE CHART (cont)

Sample No.	Temp. °F	C.D. Amps/ft^2	Agitation Yes - No	Substrate Material	Thickness (mils)	Tank No.
3.		Current Density Change at 140°F				
F-32	140	5	No	Glass	10	5
F-25	140	15	No	Glass	10	5
F-29	140	22	No	Glass	10	5
F-33	140	40	No	Glass	10	5
4.		Agitation Added at 85°F				
F-18	85	15	No	Glass	10	5
F-23	85	15	Yes	Glass	10	5
5.		Agitation Added at 100°F				
F-17	100	15	No	Glass	10	5
F-22	100	15	Yes	Glass	10	5
6.		Agitation Added at 140°F				
F-26	140	15	No	Glass	10	5
F-25	140	15	Yes	Glass	10	5
7.		Substrate Change				
F-21	100	15	No	Nickel	10	5
F-17	100	15	No	Glass	10	5
8.		Tank Change (both Norm SN Sol.)				
F-36	100	5	No	Glass	10	5
F-37	100	5	No	Glass	10	5

The resultant test coupons, three of each condition, were tested to determine physical properties. The results are shown in the Data Sheets and curves plotted from the Data Sheets included in this section.

A large number of additional specimens have been prepared but the results have not been obtained as of the compilation of this report. Information obtained to date, however, indicates beyond doubt that physical properties can be varied over a considerable range if the necessary degree of control can be obtained over the plating conditions. Appearance, grain size, tensile strength, yield strength, and even modulus of elasticity can be controlled. In the case of modulus, preliminary information indicates that this factor can be varied from over ten to thirty million as shown in Fig. 3-9. Higher current densities and higher temperature conditions produce a high modulus. Increased agitation also tends to raise the modulus. Further test results and a careful examination of the resultant information will be required before any definite statements can be made as to the degree of control over these factors which may be obtained. These parameters can, in general, be controlled, even in large production plating activities, if proper care is exercised.

The preliminary hardened copper test samples that were produced were too brittle to be tested and no information is obtainable as yet. Subsequent changes in bath composition have produced hard but less brittle electroforms. Test coupons have been prepared and are in the process of being tested. Information from these tests will be reported later.

3.2.2 Improvement in Physical Property

Preliminary information obtained from the physical property testing of the various samples indicates that variations or improvement in physical property can be achieved through careful control of the plating conditions. This possibility is extremely important relative to the design of the thin section, lightweight concentrators and support structures that have been proposed. If adequate controls can be maintained, concentrator design can be altered to take advantage of these concepts and necessary material properties can be adjusted to permit the reduction in weight of certain components with an increased ability to withstand the conditions associated with launch environment and related shock and vibration loading.

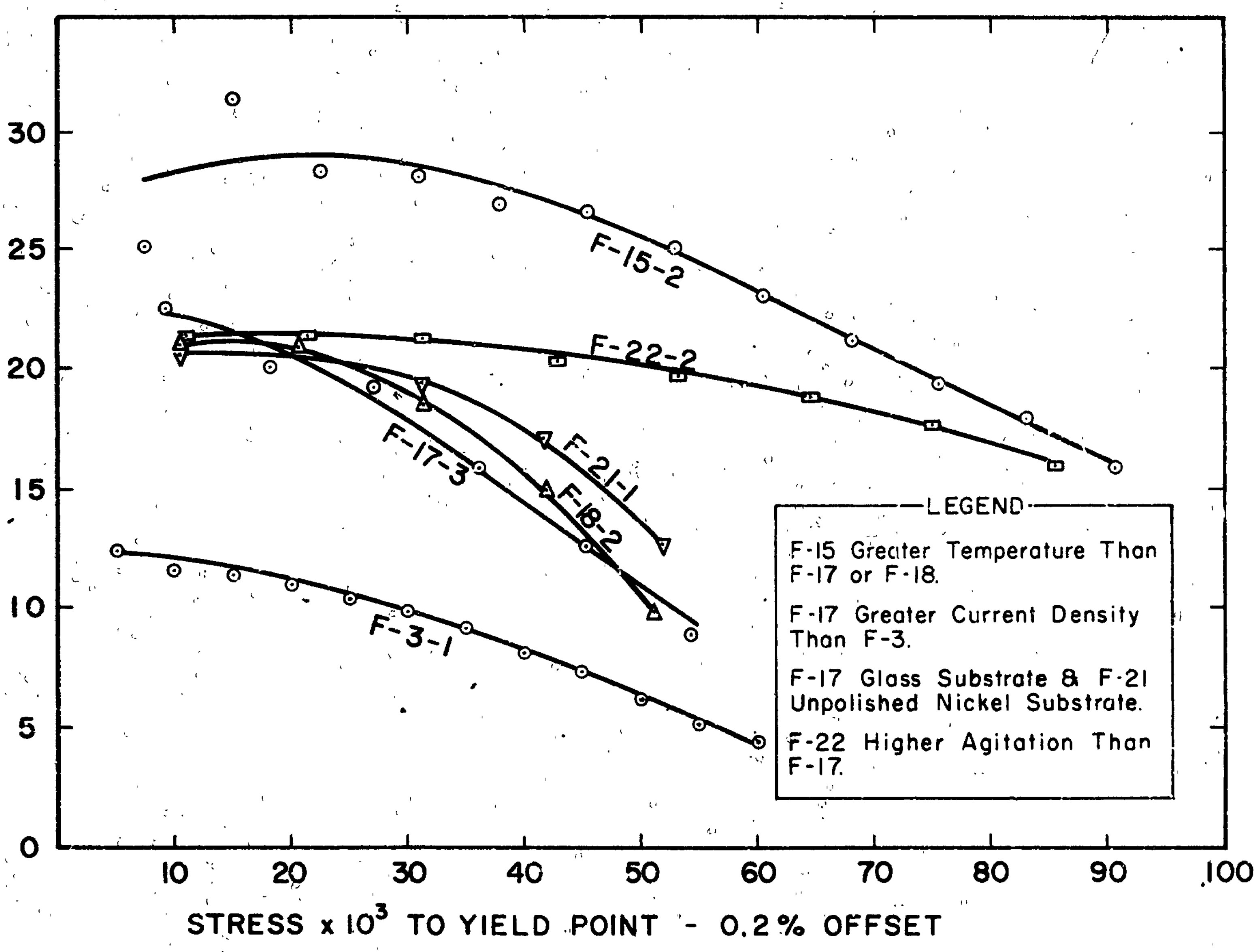

FIG. 3-9 PARAMETRIC TRENDS AFFECTING YOUNG'S MODULUS IN ELECTRODEPOSITED NICKEL

LABORATORIES CHEMICAL PHYSICAL · METALLURGICAL · QUANTOMETRIC NON DESTRUCTIVE · INSPECTION RESEARCH

METAL CONTROL LABORATORIES

INCORPORATED
2735 EAST SLAUSON AVENUE
HUNTINGTON PARK, CALIF.
LUDLOW 8-4161

CERTIFIED REPORT OF PHYSICAL TEST

FOR ACCOUNT OF: ELECTRO-OPTICAL SYSTEMS, INC. DATE: 2-22-62

YOUR P. O. No: 17307 FILE No.:

MANUFACTURED BY: SECTION No:

PRIME CONTRACTOR: MATERIAL: Plated Nickel Specimens

SUBCONTRACTOR: SPECIFICATION:

ATTN: Mr. Dale McCrary

PHYSICAL PROPERTIES

			YIELD POINT:		TENSILE STRENGTH:							
HEAT NUMBER	ACTUAL SIZE	ACTUAL AREA	ACTUAL LOAD IN LBS.	POUNDS PER SQ. IN.	ACTUAL LOAD IN LBS.	POUNDS PER SQ. IN.	ELONGATION IN 2 IN.	ELONGATION PER CENT	REDUCED DIMENSION	REDUCTION OF AREA PER CENT	CODE	LAB NO.
ROOM TEMPERATURE TENSILE TEST												22-901F
3-1	.0098 / .510	.004998	262	52400	403	80000	0.24	12				
[illegible]-2	.0094 / .510	.004794	257	53600	392	81700	0.20	10				
[illegible]-3	.0090 / .509	.004581	250	54600	383	83600	0.15	* 7.5				
MAXIMUM REQUIREMENTS												
MINIMUM REQUIREMENTS												

YIELD STRENGTH BY EXTENSOMETER AT 0.2% offset IN 2".

Code:
(F) Indicates flaw.
(G) " broke outside gauge mark
(H) " broke at gauge mark

WITNESSED BY:
☐ NAVY INSPECTOR
☐ ARMY INSPECTOR
☐

* Specimen broke at small dimple like flaw causing somewhat less elongation.

RESPECTFULLY SUBMITTED
Paul J Petius
METAL CONTROL LABORATORIES
CHEMISTS · METALLURGISTS · ENGINEERS · INSPECTORS

2100-IR-1

DATA SHEET

Date 22 Feb 1962

Sample F-3-1

Area .004998 in^2

Test No.

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress/psi	Strain/in.	E x /10^6	
25	5,000	.0004	12.5	
50	10,000	.00085	11.8	
75	15,000	.0013	11.5	
100	20,000	.0018	11.1	
125	25,000	.0024	10.4	
150	30,000	.0030	10.0	
175	35,000	.0038	9.21	
200	40,000	.0048	8.34	
225	45,000	.0062	7.26	
250	50,000	.0080	6.25	
275	55,000	.0104	5.28	
300	60,000	.0136	4.42	
325				
350				
375				
400				
425				
450				
475				
500				
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

DATA SHEET

Sample F-3-2

Area .004794 in^2

ELECTRO-OPTICAL SYSTEMS, INC.

Page 1 of 1

Date 22 Feb 1962

Test No.

By Metal Control Laboratories, Inc.

W.A. 2100

Load/lbs	Stress/psi	Strain/in.	E x 10^6	
25	5,220	.0005	10.4	
50	10,450	.0009	11.6	
75	15,700	.0015	10.4	
100	20,800	.0019	10.9	
125	26,100	.0025	10.4	
150	31,300	.0033	10.5	
175	36,600	.0042	8.72	
200	41,700	.0053	7.87	
225	47,000	.0067	7.02	
250	52,200	.0085	6.15	
275	57,500	.0110	5.23	
300	62,700	.0147	4.26	
325				
350				
375				
400				
425				
450				
475				
500				
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

DATA SHEET

Page 1 of 1

Date 22 Feb 1962

Sample F-3-3

Test No.

Area .004581 in^2

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress/psi	Strain/in.	E x 10^6	
25	5,480	.0005	10.9	
50	10,900	.0009	12.1	
75	16,800	.0014	12.0	
100	21,800	.0020	10.9	
125	27,300	.0026	10.5	
150	32,800	.0033	9.95	
175	38,200	.0042	9.09	
200	43,700	.0053	8.25	
225	49,200	.0069	7.14	
250	53,500	.0090	5.9[illegible]	
275	60,000	.0117	5.13	
300	64,200	.0157	4.08	
325				
350				
375				
400				
425				
450				
475				
500				
525				
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575				
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625				
650				
675				
700				
725				
750				
775				
800				

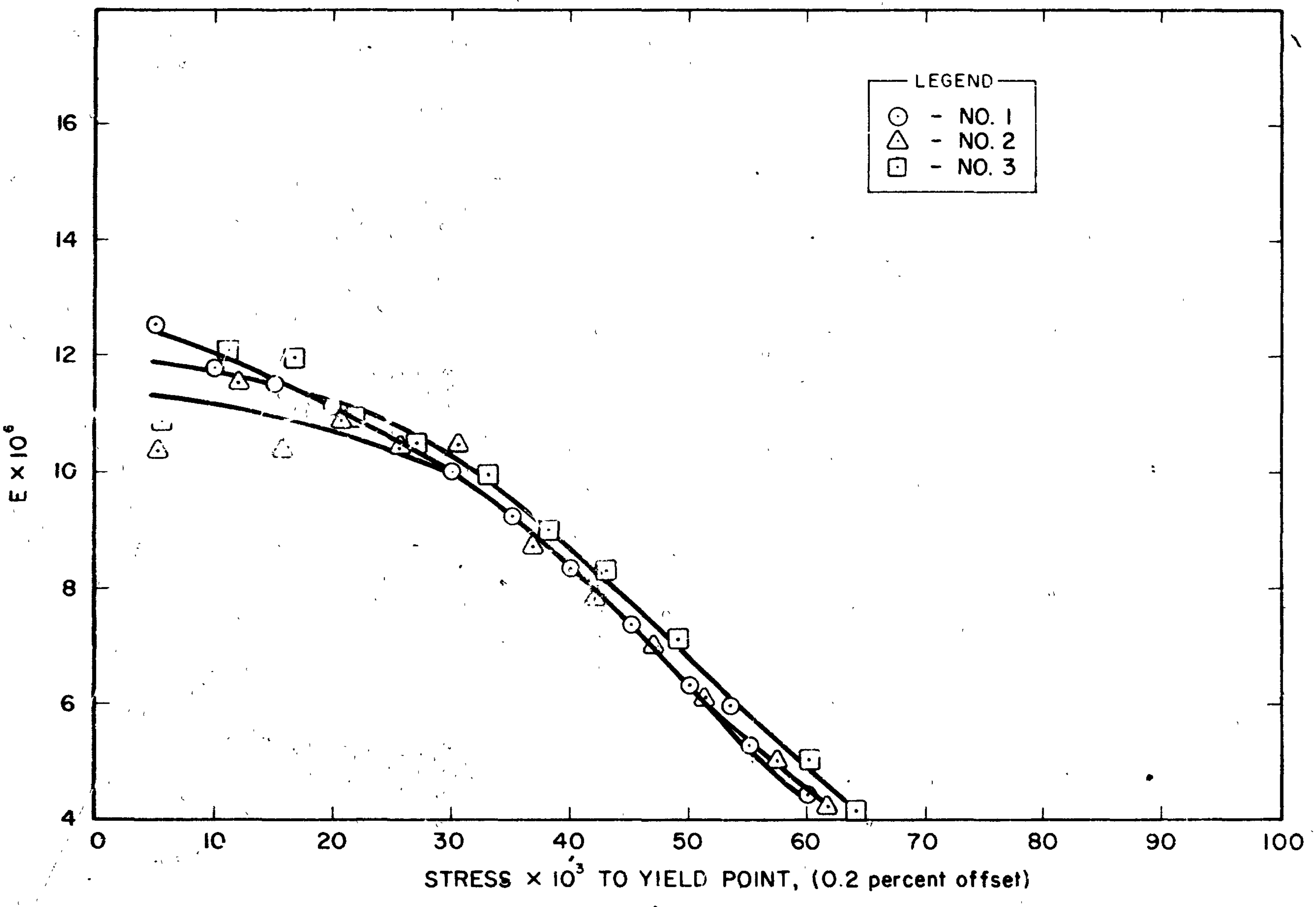

FIG. 3-10 SAMPLE F-3

LABORATORIES CHEMICAL PHYSICAL METALLURGICAL QUANTOMETRIC - NON DESTRUCTIVE - INSPECTION - RESEARCH

METAL CONTROL LABORATORIES

INCORPORATED
2735 EAST SLAUSON AVENUE
HUNTINGTON PARK CALIF
LUDLOW 8-4161

CERTIFIED REPORT OF PHYSICAL TEST

FOR ACCOUNT OF | DATE

YOUR P. O. NO | FILE NO

MANUFACTURED BY: | SECTION NO

PRIME CONTRACTOR | MATERIAL

SUBCONTRACTOR | SPECIFICATION

PHYSICAL PROPERTIES

HEAT NUMBER	ACTUAL SIZE	ACTUAL AREA	YIELD POINT: ACTUAL LOAD IN LBS.	YIELD POINT: POUNDS PER SQ. IN.	TENSILE STRENGTH: ACTUAL LOAD IN LBS	TENSILE STRENGTH: POUNDS PER SQ. IN.	ELONGATION IN 2 IN.	ELONGATION PER CENT	REDUCED DIMENSION	REDUCTION OF AREA PER CENT	CODE	LAB NO.
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]
MAXIMUM REQUIREMENTS												
MINIMUM REQUIREMENTS												

LD STRENGTH BY EXTENSOMETER AT IN 2".

de.
indicates flaw
" broke outside gauge mark
broke at gauge mark

WITNESSED BY:
NAVY INSPECTOR
ARMY INSPECTOR

RESPECTFULLY SUBMITTED

METAL CONTROL LABORATORIES
CHEMISTS - METALLURGISTS - ENGINEERS - INSPECTORS

2100-IR-1

		DATA SHEET	Page 1 of 1	
			Date 21 Mar 1962	
	Sample	F - 15-1	Test No.	
	Area	.006677 in^2	By Metal Control Laboratories, Inc.	

ELECTRO-OPTICAL SYSTEMS, INC.

W. A. 2100

Load/lbs	Stress psi	Strain [illegible]	E x [illegible]	
25	3,745	.00012	31.2	
50	7,500	.00024	31.2	
75	11,220	.00037	30.4	
100	15,000	.0005	30.00	
125	18,720	.0006	31.10	
150	22,420	.0008	28.02	
175	26,220	.0009	29.15	
200	29,900	.0010	29.90	
225	33,700	.0012	28.10	
250	37,420	.0014	27.80	
275	41,200	.00155	26.58	
300	45,000	.00175	25.70	
325	48,700	.0019	25.60	
350	52,400	.00215	24.38	
375	56,200	.00235	23.90	
400	59,800	.0026	23.02	
425	63,700	.0029	21.94	
450	67,400	.0032	21.08	
475	71,200	.0035	20.32	
500	74,900	.0038	19.70	
525	78,600	.0042	18.70	
550	82,400	.0046	17.90	
575	86,100	.0050	17.20	
600	89,900	.0055	16.35	
625				
650				
675				
700				
725				
750				
775				
800				

2100-IR-1

DATA SHEET

Page 1 of 1

Date 21 Mar 1962

Sample 15-2

Test No.

Area .006626 in^2

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress/psi	Strain/in.	E x 10^6	
25	3,778	.00012	31.40	
50	7,540	.00025	30.10	
75	11,320	.0004	28.39	
100	15,080	.0005	30.05	
125	18,850	.00065	29.00	
150	22,600	.0008	28.30	
175	26,400	.0009	29.32	
200	30,150	.0011	27.42	
225	33,980	.0012	28.30	
250	37,700	.0014	26.90	
275	41,600	.0016	25.95	
300	45,500	.0018	25.10	
325	49,000	.0020	24.47	
350	52,800	.0022	24.00	
375	56,600	.0024	23.58	
400	60,250	.0026	23.15	
425	64,100	.0029	22.05	
450	68,000	.0032	21.22	
475	71,700	.0035	20.45	
500	75,400	.0039	19.35	
525	79,200	.0042	18.85	
550	82,900	.0046	18.05	
575	86,500	.0050	17.30	
600	90,500	.0055	16.45	
625				
650				
675				
700				
725				
750				
775				
800				

2100-IR-1

DATA SHEET

Page 1 of 1

Date 21 Mar 1962

Sample 15-3

Test No.

Area .006526 in^2

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress/psi	Strain/in.	$E \times 10^6$	
25	3,450	.00013	26.50	
50	7,660	.0003	25.50	
75	11,490	.0004	28.78	
100	15,320	.0006	25.56	
125	19,110	.0007	27.30	
150	22,950	.0008	28.70	
175	26,800	.0010	26.80	
200	30,310	.0012	25.50	
225	34,450	.00135	25.45	
250	38,300	.00155	24.70	
275	42,200	.0017	24.70	
300	45,900	.0019	24.20	
325	49,800	.0021	23.70	
350	53,500	.0023	23.30	
375	57,400	.0026	22.05	
400	61,250	.0028	21.85	
425	65,000	.0031	20.95	
450	68,900	.0034	20.25	
475	72,800	.0037	19.65	
500	76,400	.0041	18.62	
525	80,400	.0044	18.25	
550	84,200	.0049	17.18	
575	88,000	.0053	16.62	
600	91,700	.0059	15.55	
625				
650				
675				
700				
725				
750				
775				
800				

2100-IR-1

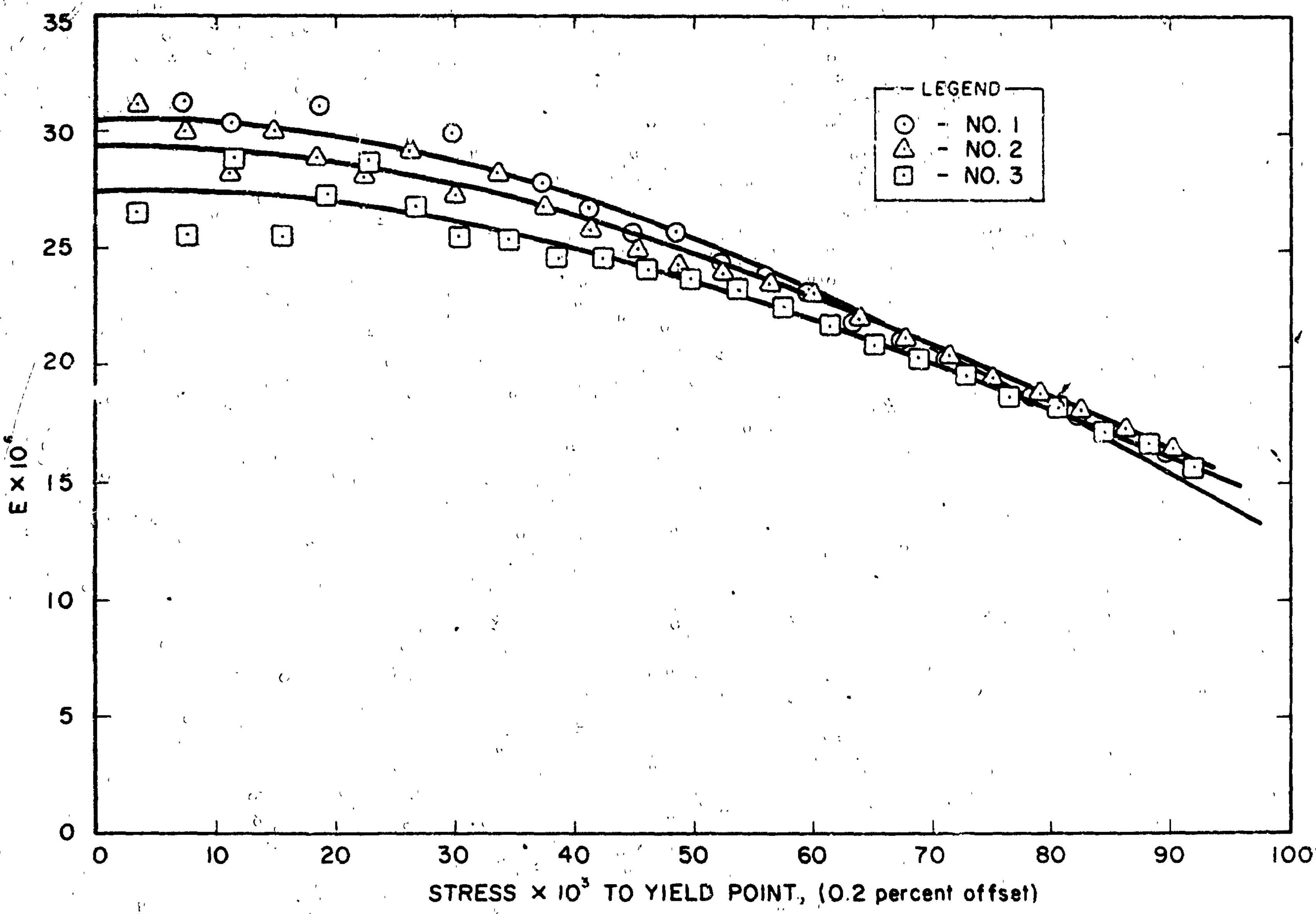

FIG. 3-11 SAMPLE F-15

DATA SHEET

Date 21 Mar 1962

Sample F - 17-1

Area .005522 in^2

Test No.

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress/psi	Strain/in.	$E \times 10^6$	
25	4,525	.0002	22.6	
50	4,800	.0004	22.6	
75	13,550	.00065	20.8	
100	18,100	.0009	20.1	
125	22,600	.0011	20.6	
150	27,200	.0014	19.4	
175	31,650	.0019	16.7	
200	36,120	.0022	16.45	
225	40,800	.0027	15.1	
250	45,300	.0035	12.9	
275	49,900	.0045	11.05	
300	54,400	.0006	9.05	
325				
350				
375				
400				
425				
450				
475				
500				
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

DATA SHEET

Page 1 of 1

Date 21 Mar 1962

Sample 17-2

Test No.

Area .005522 in^2

By Metal Control Laboratories, Inc.

EOS ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress/psi	Strain/in.	E x 10^6	
25	4,525	.0002	22.6	
50	9,050	.0004	22.6	
75	13,550	.0006	22.6	
100	18,100	.0008	22.6	
125	22,600	.0010	22.6	
150	27,190	.0012	22.6	
175	31,650	.0014	22.6	
200	36,120	.0017	21.3	
225	40,750	.0023	17.7	
250	45,250	.0031	14.6	
275	49,480	.0041	12.15	
300	54,400	.0057	9.6	
325				
350				
375				
400				
425				
450				
475				
500				
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

DATA SHEET

Page 1 of 1

Date 21 Mar 1962

Sample 17-3

Test No.

Area .005522 in^2

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress/psi	Strain/in.	E x 10^6	
25	4,530	.0002	22.6	
50	9,050	.00045	20.1	
75	13,580	.0007	19.4	
100	18,150	.0009	20.1	
125	22,650	.0011	20.6	
150	27,200	.00145	18.75	
175	31,250	.0018	17.6	
200	36,300	.0023	15.75	
225	40,700	.0028	14.55	
250	45,250	.0036	12.55	
275	49,800	.0047	10.6	
300				
325				
350				
375				
400				
425				
450				
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725				
750				
775				
800				

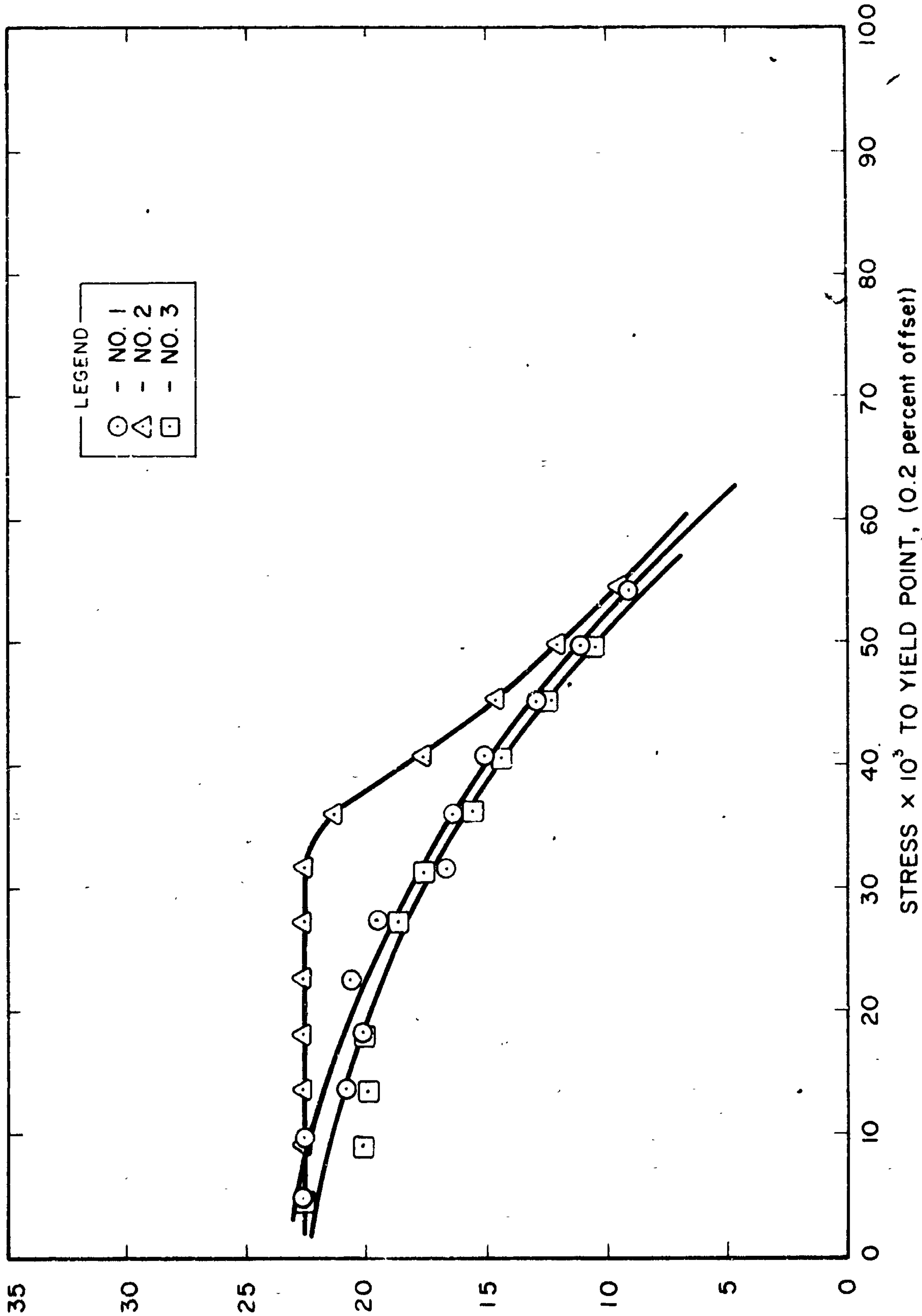

FIG. 3-12 SAMPLE F-17

DATA SHEET

Date 21 Mar 1962

Sample F - 18-1

Test No.

Area .004618 in^2

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress/psi	Strain/in.	E x 10^6	
25	5,430	.0003	18.1	
50	10,810	.0006	18.0	
75	16,250	.0009	18.05	
100	21,610	.0012	17.95	
125	27,150	.00148	18.3	
150	32,500	.0018	18.0	
175	37,950	.0022	17.4	
200	43,400	.0028	16.1	
225	48,800	.0036	13.55	
250	54,200	.0048	11.3	
275	59,600	.007	8.5	
300				
325				
350				
375				
400				
425				
450				
475				
500				
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

DATA SHEET

Page 1 of 1

Date 21 Mar 1962

Sample 18-2

Test No.

Area .004769 in^2

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress/psi	Strain/in.	$E \times 10^6$	
25	5,230	.00025	20.9	
50	10,490	.0005	20.9	
75	15,750	.0008	19.7	
100	20,950	.0010	20.95	
125	26,200	.0013	20.9	
150	31,500	.0017	18.5	
175	36,650	.00215	17.05	
200	40,990	.0028	15.0	
225	47,200	.0038	12.4	
250	52,400	.0053	9.9	
275				
300				
325				
350				
375				
400				
425				
450				
475				
500				
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

DATA SHEET

Page 1 of 1

Date 21 Mar 1962

Sample 18-3

Area .004769 in^2

Test No.

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lb.	Stress/psi	Strain/in.	E x 10^6	
25	5,240	.0002	26.2	
50	10,490	.0005	21.0	
75	15,700	.0008	19.6	
100	20,950	.00105	20.8	
125	26,200	.0013	20.1	
150	31,400	.0017	18.45	
175	36,650	.0022	16.7	
200	41,950	.0029	14.45	
225	47,100	.0040	11.8	
250	52,400	.0058	9.1	
275				
300				
325				
350				
375				
400				
425				
450				
475				
500				
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

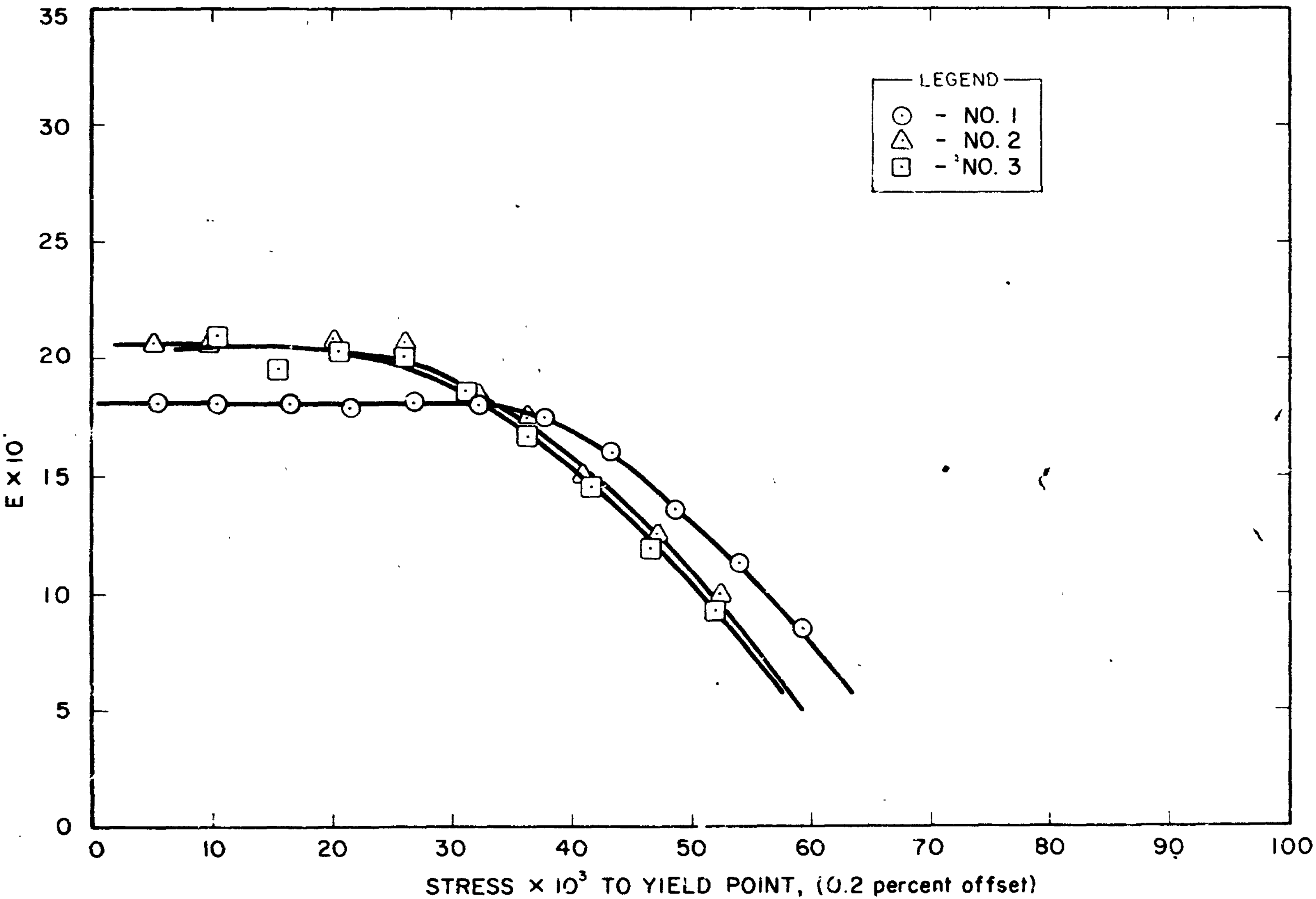

FIG. 3-13 SAMPLE F-18

LABORATORIES · CHEMICAL · PHYSICAL · METALLURGICAL · QUANTOMETRIC · NON DESTRUCTIVE · INSPECTION · RESEARCH

METAL CONTROL LABORATORIES

INCORPORATED
2735 EAST SLAUSON AVENUE
HUNTINGTON PARK CALIF.
LUDLOW 2 4161

CERTIFIED REPORT OF PHYSICAL TEST

FOR ACCOUNT OF [illegible] | DATE [illegible]

YOUR P. O. NO. [illegible] | FILE NO.

MANUFACTURER | SECTION NO.

PRIME CONTRACTOR | MATERIAL [illegible]

SUBCONTRACTOR | SPECIFICATION [illegible]

[illegible]

PHYSICAL PROPERTIES

HEAT NUMBER	ACTUAL SIZE	ACTUAL AREA	YIELD POINT: ACTUAL LOAD IN LBS.	YIELD POINT: POUNDS PER SQ. IN.	TENSILE STRENGTH: ACTUAL LOAD IN LBS.	TENSILE STRENGTH: POUNDS PER SQ. IN.	ELONGATION IN 2 IN.	ELONGATION PER CENT	REDUCED DIMENSION	REDUCTION OF AREA PER CENT	CODE	LAB NO.
[illegible]												
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	
2	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]				
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
MAXIMUM REQUIREMENTS												
MINIMUM REQUIREMENTS												

YIELD STRENGTH BY EXTENSOMETER AT [illegible] IN 2".

Code.
(F) indicates flaw
(G) " broke outside gauge mark
(9) " broke at gauge mark

WITNESSED BY:

NAVY INSPECTOR All specimens except [illegible]-1 had [illegible] taper

ARMY INSPECTOR in thickness near end of reduced section.

RESPECTFULLY SUBMITTED

METAL CONTROL LABORATORIES
CHEMISTS · METALLURGISTS · ENGINEERS · INSPECTORS

DATA SHEET

Date 21 Mar 1962

Sample 21-1

Test No.

Area .004819 in^2

By Metal Control Laboratories, Inc.

EOS ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load, lbs	Stress, psi	Str[illegible]	[illegible]	
25	5,180	.00025	20.7	
50	10,350	.0005	20.7	
75	15,520	.0007	22.2	
100	20,700	.0010	20.7	
125	25,900	.0012	21.6	
150	31,100	.00155	20.05	
175	36,300	.002	18.15	
200	41,500	.0025	16.6	
225	46,700	.0032	14.6	
250	51,900	.0042	12.3	
275	57,100	.0062	9.2	
300				
325				
350				
375				
400				
425				
450				
475				
500				
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

EOS FORM [illegible]

DATA SHEET

Page 1 of 1

Date 21 Mar 1962

Sample 21-2

Test No.

Area .004769 in^2

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W. A. 2100

[illegible]	[illegible]	[illegible]	[illegible]	
25	5,240	.00025	20.9	
50	10,480	.0005	20.9	
75	15,710	.0008	19.65	
100	20,950	.0001	20.9	
125	26,200	.0013	20.2	
150	31,400	.00165	19.0	
175	36,600	.0021	17.45	
200	41,900	.0026	16.1	
225	47,200	.0034	13.85	
250	52,400	.0043	12.2	
275	57,600	.0062	9.3	
300				
325				
350				
375				
400				
425				
450				
475				
500				
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

2100-IR-1

DATA SHEET

Date 21 Mar 1962

Sample 21-3

Test No.

Area .004920 in^2

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load, lbs	Stress (psi)	Strain in.	[illegible]	
25	5,080	.00025	20.3	
50	10,160	.0005	20.4	
75	15,220	.0007	21.8	
100	20,300	.00095	21.4	
125	25,400	.0012	21.2	
150	30,500	.0015	20.3	
175	35,600	.002	17.8	
200	40,600	.0025	16.25	
225	45,600	.0032	14.3	
250	50,800	.0042	12.1	
275	55,900	.0056	9.99	
300				
325				
350				
375				
400				
425				
450				
475				
500				
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

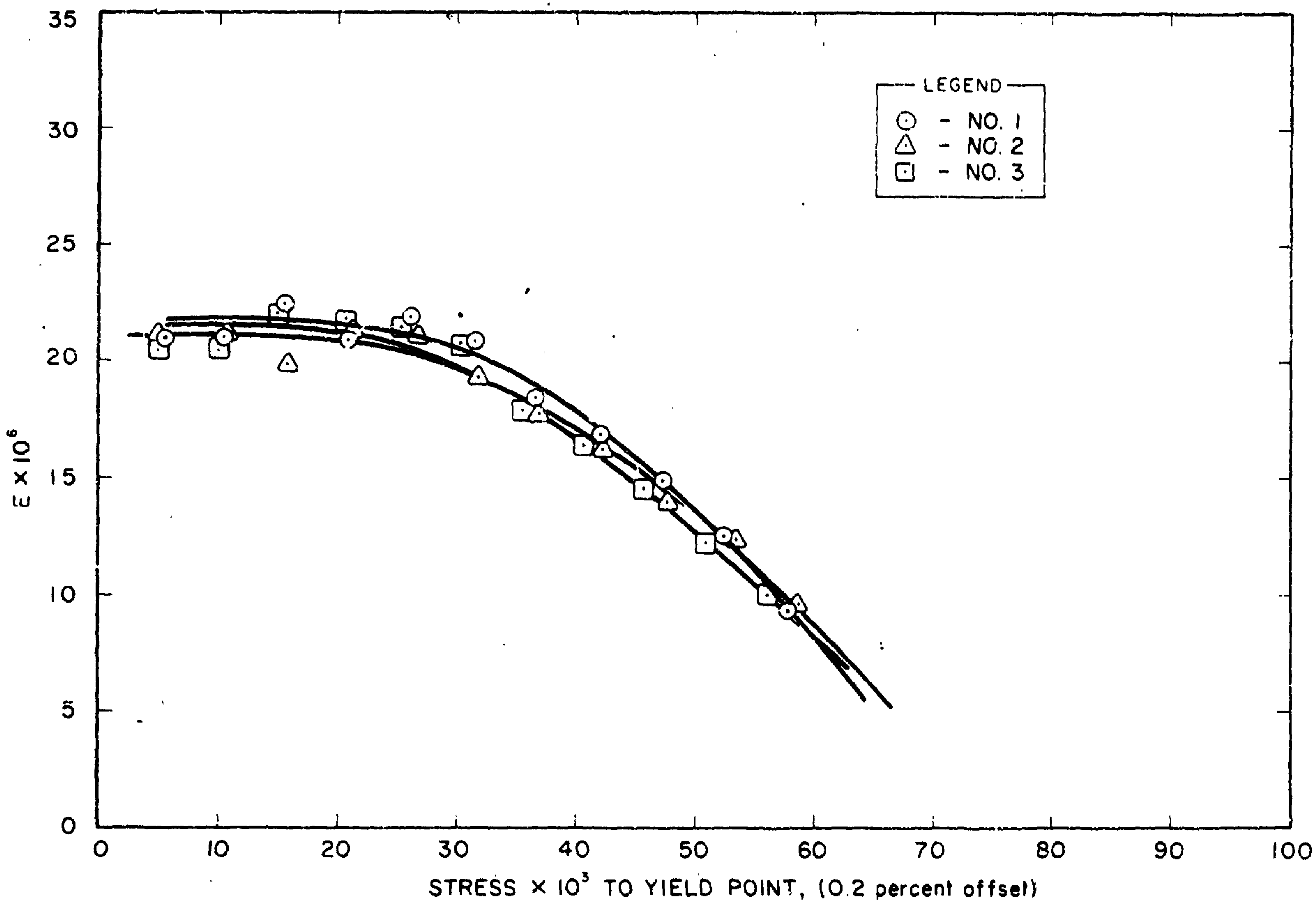

FIG. 3-14 SAMPLE F-21

DATA SHEET

Page 1 of 1

Date 21 Mar 1962

Sample 22-1

Area .004669 in^2

Test No.

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress psi	Strain in/in	[illegible]	
25	5,350	.00022	24.3	
50	10,700	.00045	23.8	
75	16,050	.0007	22.9	
100	21,400	.0009	23.8	
125	26,200	.0011	23.8	
150	32,100	.00135	23.8	
175	37,400	.0016	23.4	
200	42,800	.0019	22.6	
225	48,100	.0022	21.9	
250	53,500	.0025	21.4	
275	58,900	.0028	21.0	
300	64,200	.0032	20.1	
325	69,600	.0036	19.3	
350	74,900	.0041	18.25	
375	80,300	.0047	17.1	
400	85,600	.0053	16.16	
425	90,900	.0061	14.9	
450				
475				
500				
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

2100-IR-1

EOS F[illegible] 247 (REV)

DATA SHEET

Date 21 Mar 1962

Sample 22-2

Area .004669 in^2

Test No. -

By Metal Control Laboratories, Inc.

W.A. 2100

ELECTRO-OPTICAL SYSTEMS, INC.

Load/lbs	Stress/psi	Strain/in/in.	$E \times 10^6$	
25	5,360	.00025	21.4	
50	10,700	.0005	21.4	
75	16,050	.00075	21.4	
100	21,400	.0010	21.4	
125	26,700	.00125	21.4	
150	32,100	.0015	21.4	
175	37,400	.0018	20.8	
200	42,900	.0020	21.45	
225	48,100	.00235	20.5	
250	53,500	.0026	20.5	
275	59,000	.0030	19.65	
300	64,200	.0034	18.9	
325	69,600	.0038	18.3	
350	75,000	.0042	17.85	
375	80,200	.00465	17.25	
400	85,700	.0053	16.2	
425	91,000	.0059	15.4	
450	96,200	.0067	14.4	
475				
500				
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

2100-IR-1

DATA SHEET

Date 21 Mar 1962

Sample 22-3

Area .004669 in^2

Test No.

By Metal Control Laboratories, Inc

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load, lbs	Stress/psi	Strain, in.	$E \times 10^6$	
25	5,350	.00022	24.3	
50	10,700	.00045	23.8	
75	16,000	.0007	22.9	
100	21,400	.00094	22.8	
125	26,800	.0012	22.3	
150	32,200	.0014	22.9	
175	37,400	.00162	23.2	
200	42,900	.00185	23.2	
225	48,200	.0022	21.9	
250	53,500	.0025	21.4	
275	59,000	.0028	21.0	
300	64,400	.0030	21.4	
325	69,500	.0036	19.3	
350	75,000	.0040	18.75	
375	80,400	.0046	17.45	
400	85,580	.0052	16.5	
425	91,000	.0060	15.14	
450	96,200	.0069	13.95	
475				
500				
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

EOS FORM 247 (REV.)

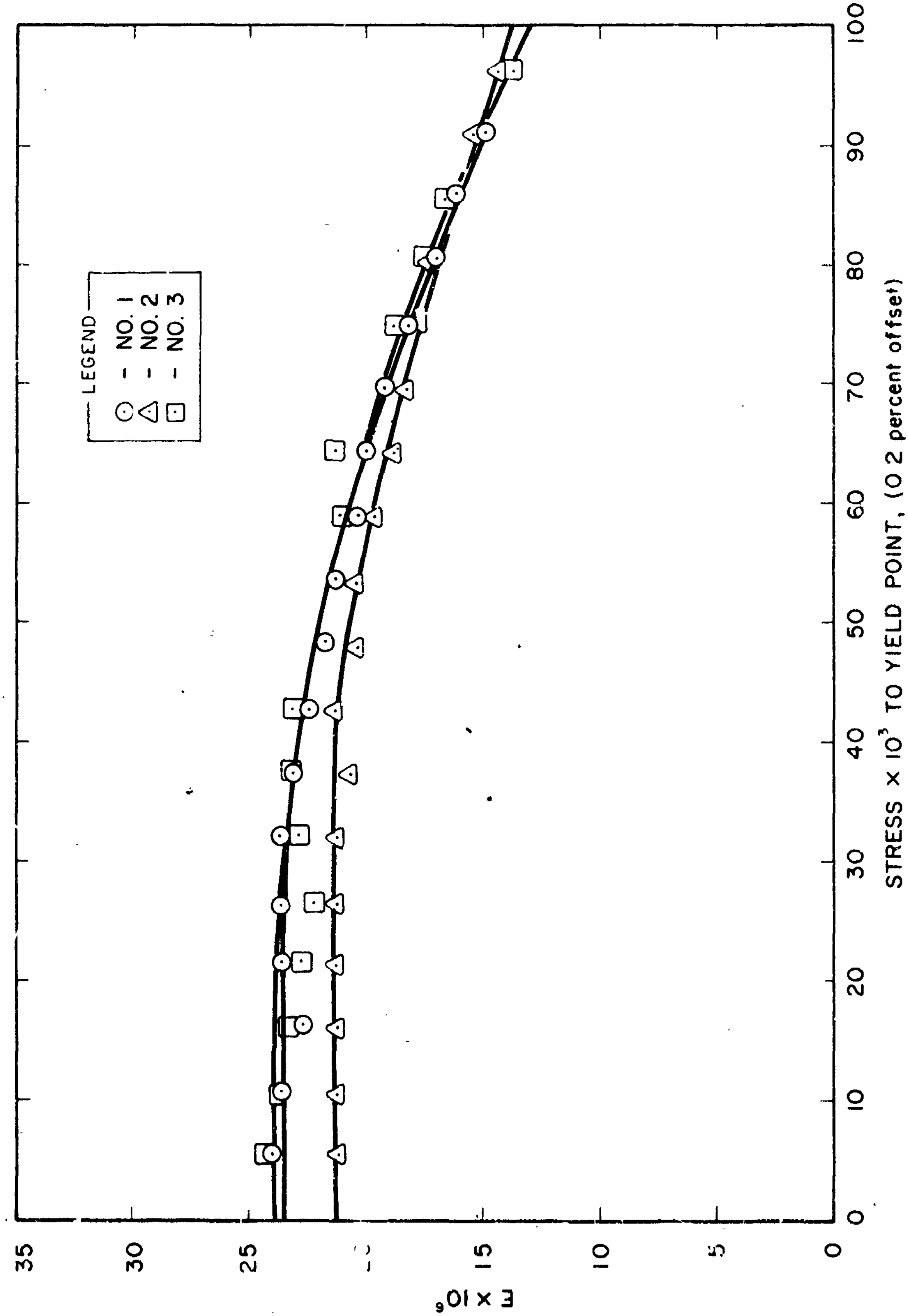

FIG. 3-15 SAMPLE F-22

METAL CONTROL LABORATORIES

INCORPORATED
2735 EAST SLAUSON AVENUE
HUNTINGTON PARK CALIF.
LUDLOW 8-4161

CERTIFIED REPORT OF PHYSICAL TEST

FOR ACCOUNT OF: ELECTRO OPTICAL SYSTEMS
DATE: [illegible]

YOUR P O No: 13195, Shipper [illegible]
FILE No.

MANUFACTURED BY:
SECTION No.

PRIME CONTRACTOR:
MATERIAL: Electro deposited nickel specimens

SUBCONTRACTOR:
SPECIFICATION

ATTN: Mr. W. D. McCary

PHYSICAL PROPERTIES

HEAT NUMBER	ACTUAL SIZE	ACTUAL AREA	YIELD POINT: ACTUAL LOAD IN LBS.	YIELD POINT: POUNDS PER SQ. IN	TENSILE STRENGTH: ACTUAL LOAD IN LBS.	TENSILE STRENGTH: POUNDS PER SQ. IN.	ELONGATION IN 2 IN.	ELONGATION PER CENT	REDUCED DIMENSION	REDUCTION OF AREA PER CENT	CODE	LAB NO.
ROOM TEMPERATURE TENSILE TESTS												
F-23												
1	.496 / .0094	.004662	378	81100	535	115000	0.08	4				42-128F
2	.497 / .0093	.004622	386	83500	538	116000	0.08	4				
3	.497 / .0093	.004622	426*	92200	530	115000	0.10	5				
F-25												
1	.497 / .0088	.004374	435	99400	636	145000	0.08	4				
2	.497 / .0088	.004374	430	98300	636	145000	0.08	4				
3	.497 / .0088	.004379	458	105000	642	147000	0.10	5				
MAXIMUM REQUIREMENTS												
MINIMUM REQUIREMENTS												

YIELD STRENGTH BY EXTENSOMETER AT 0.2% Offset IN 2".

* Yield approximate due to extensometer malfunction.

Code:
(F) Indicates flow
(G) " broke outside gauge mark
(g) " broke at gauge mark

WITNESSED BY:
NAVY INSPECTOR
ARMY INSPECTOR

2100-IR-1

RESPECTFULLY SUBMITTED
[signature]
METAL CONTROL LABORATORIES
CHEMISTS - METALLURGISTS - ENGINEERS - INSPECTORS

DATA SHEET

Date 6 April 1962

Sample F-23-1

Test No.

Area .004662 in^2

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress/psi	Strain/in.	Y	
25	5,370	.0002	26.85	
50	10,720	.0004	26.80	
75	16,100	.0006	26.80	
100	21,400	.0008	26.75	
125	26,850	.0010	26.85	
150	32,200	.00130	24.80	
175	27,600	.00155	24.20	
200	43,000	.00185	23.20	
225	48,300	.00215	22.50	
250	53,700	.0025	21.50	
275	59,000	.0029	20.35	
300	64,500	.00325	19.85	
325	69,750	.0039	17.90	
350	75,200	.0044	17.10	
375	80,500	.00515	15.65	
400	85,800	.0060	14.32	
425				
450				
475				
500				
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

2100-IR-1

DATA SHEET

Page 1 of 1

Date 6 April 1962

Sample F-23-2

Test No.

Area .004622 in^2

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress/psi	Strain/in.	$E \times 10^6$	
25	5,420	.00022	24.65	
50	10,830	.00043	25.20	
75	16,250	.00064	25.35	
100	21,620	.00087	24.90	
125	27,100	.00110	24.62	
150	32,500	.00136	23.90	
175	37,900	.00160	23.70	
200	43,400	.00190	22.82	
225	48,700	.00220	22.10	
250	54,050	.00258	20.95	
275	59,500	.00294	20.25	
300	64,950	.00340	19.10	
325	70,400	.00390	18.05	
350	75,800	.00450	16.85	
375	81,100	.00522	15.52	
400	86,600	.00612	14.15	
450				
475				
500				
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

EOS FORM 247 (REV.)

DATA SHEET

Date 6 April 1962

Sample F-23-3

Test No.

Area .004022 in^2

B. Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

[illegible]	[illegible]		[illegible]	
25	5,405	.00022	24.58	
50	10,810	.00042	25.75	
75	16,400	.00065	24.95	
100	21,620	.0009	24.10	
125	27,050	.00111	24.35	
150	32,400	.00138	23.50	
175	37,800	.00162	23.35	
200	43,400	.00188	23.05	
225	48,700	.00212	23.00	
250	54,100	.00245	22.10	
275	59,550	.00282	20.95	
300	64,900	.00321	20.10	
325	70,400	.00366	19.40	
350	75,700	.00411	18.45	
375	81,100	.00460	17.62	
400	86,500	.00521	16.60	
425	91,900	.00590	15.55	
450				
475				
500				
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

2100-IR-1

EOS FORM 247 (REV.)

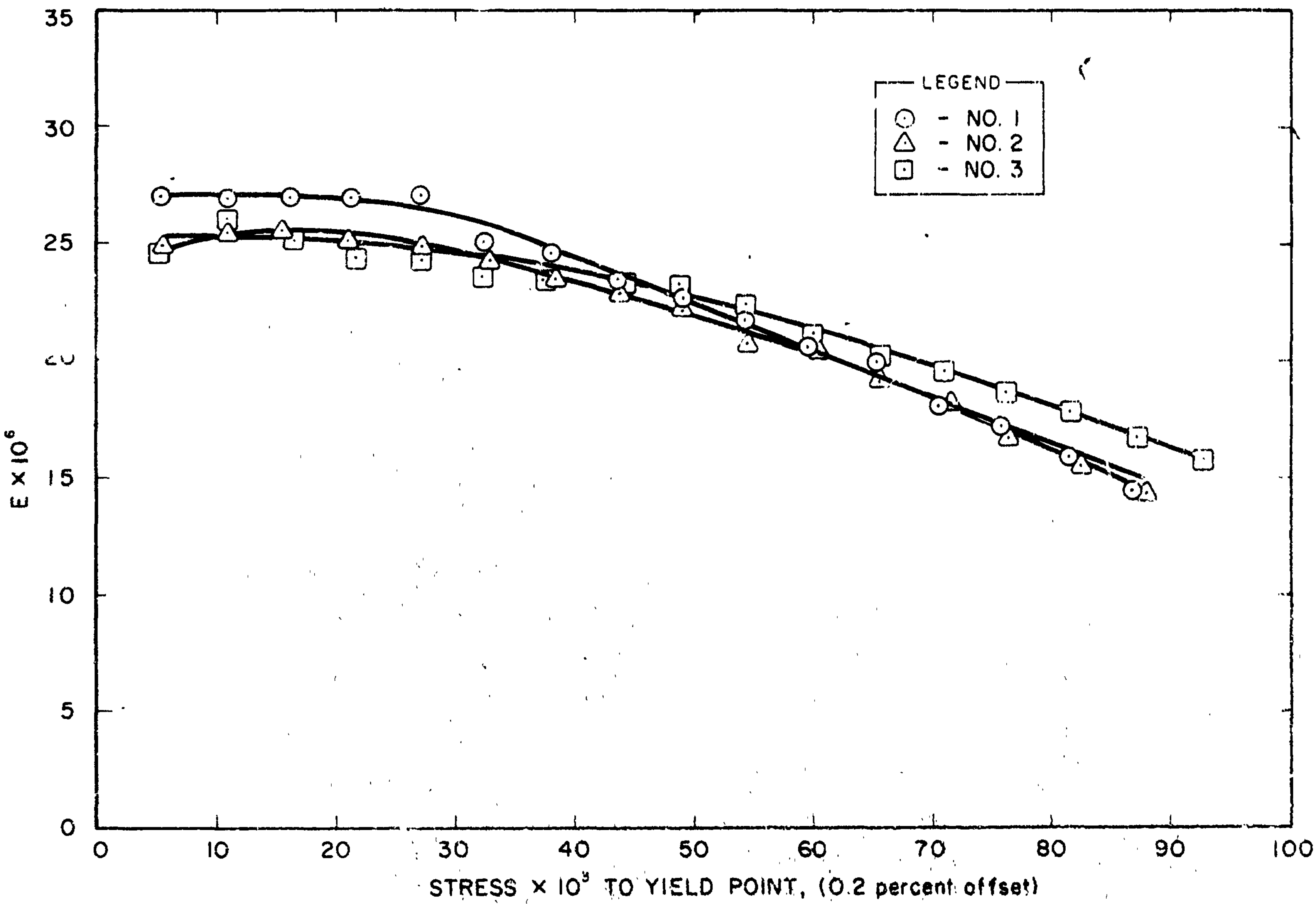

FIG. 3-16 SAMPLE F-23

DATA SHEET

Page 1 of 1

Date 6 April 1962

Sample F-25-1

Area .004374 in^2

Test No.

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W. A. 2100

Load, lbs	Stress, psi	Strain, in.	[illegible]	
25	5,720	.00025	22.8	
50	11,430	.00048	23.8	
75	17,350	.00074	23.2	
100	22,820	.00097	23.6	
125	28,600	.00121	23.6	
150	34,300	.00150	22.8	
175	40,100	.00180	22.2	
200	45,700	.00210	21.8	
225	51,500	.00240	21.4	
250	57,200	.00275	20.8	
275	62,900	.00312	20.2	
300	68,600	.00352	19.5	
325	74,400	.00392	19.0	
350	80,000	.00439	18.2	
375	85,800	.00488	17.6	
400	91,500	.00542	16.9	
425	97,200	.00602	16.1	
450	103,000	.00672	15.3	
475				
500				
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

EOS FORM 247 (REV.)

DATA SHEET

Page [illegible] of 1

Date 6 April 1962

Sample F-25-2

Area .004374 in^2

Test No.

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress psi	Strain [illegible]	E [illegible]	
25	5,720	.00020	28.6	
50	11,400	.00045	25.3	
75	1[illegible],150	.00068	25.1	
100	22,900	.00090	25.4	
125	28,600	.00115	24.8	
150	34,400	.00140	24.5	
175	40,000	.00170	23.6	
200	45,800	.00199	23.0	
225	51,500	.00230	22.4	
250	57,200	.00264	21.6	
275	63,000	.00302	20.8	
300	68,700	.00342	20.1	
325	74,400	.00382	19.5	
350	80,100	.00425	18.8	
375	85,800	.00478	17.[illegible]	
400	91,500	.0053	17.[illegible]	
425	97,200	.0059	16.5	
450	103,000	.0066	15.6	
475				
500				
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

EOS FORM 247 (REV.)

DATA SHEET

Date 6 April 1962

Sample F-25-3

Test No. ______

Area .004379 in^2

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress/psi	Strain, in.	E × 10^6	
25	5,710	.00025	22.8	
50	11,150	.00050	22.4	
75	17,130	.00076	22.6	
100	22,800	.00102	22.4	
125	28,550	.00132	21.6	
150	34,200	.00160	21.4	
175	40,000	.00188	21.1	
200	45,800	.00220	20.8	
225	51,500	.00255	20.2	
250	57,100	.00285	20.0	
275	62,900	.00322	19.5	
300	68,500	.00362	18.9	
325	74,200	.00403	18.4	
350	80,000	.00448	17.8	
375	85,700	.00496	17.3	
400	91,400	.00550	16.6	
425	97,000	.00610	15.9	
450	103,000	.00675	15.2	
475	108,500	.00750	14.5	
500				
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

2100-IR-1

EOS FORM 247 (REV.)

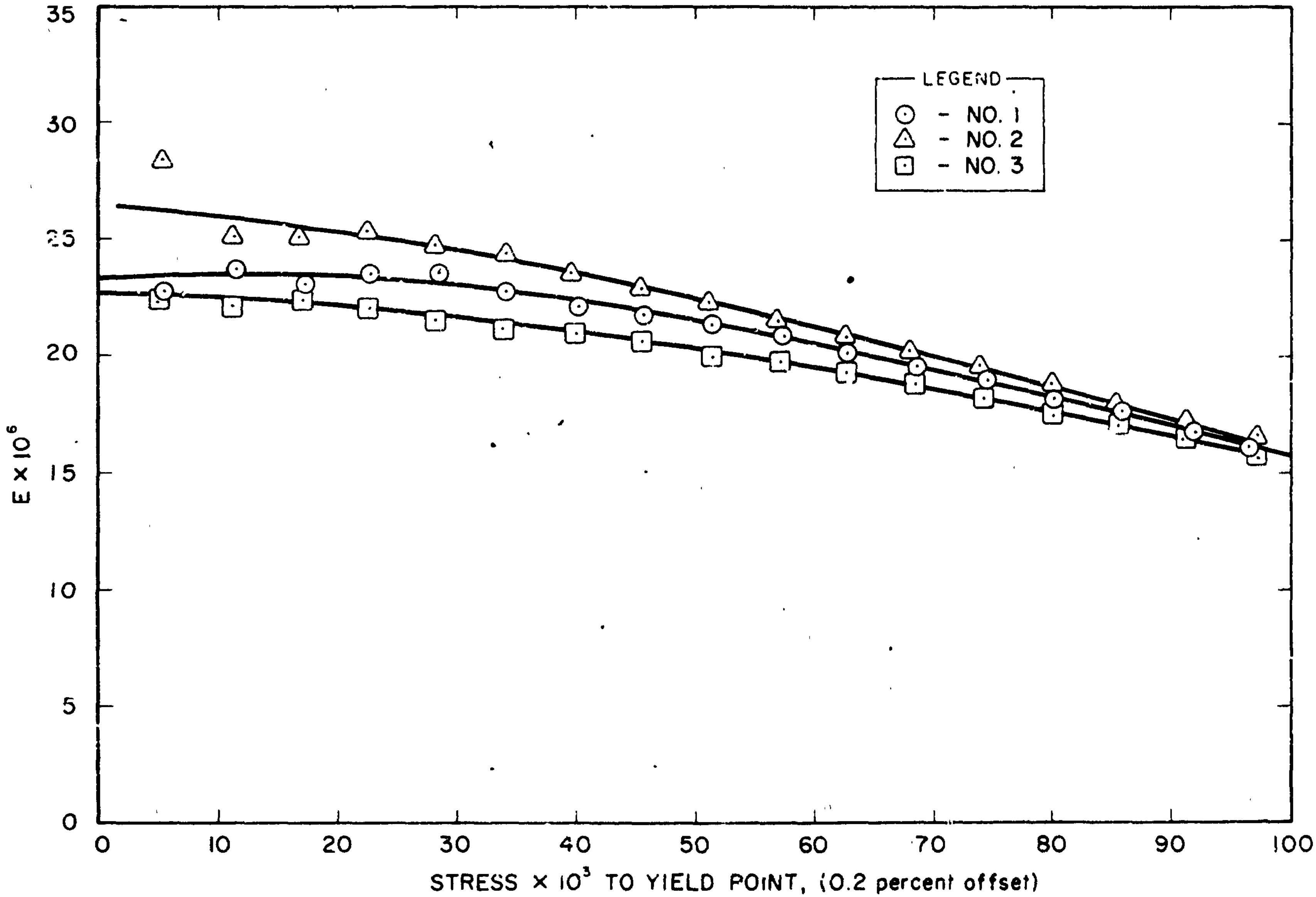

FIG. 3-17 SAMPLE F-25-1

METAL CONTROL LABORATORIES
INCORPORATED
2735 EAST SLAUSON AVENUE
HUNTINGTON PARK, CALIF.
LUDLOW 8-4161

CERTIFIED REPORT OF PHYSICAL TEST

FOR ACCOUNT OF: ELECTRO-OPTICAL SYSTEMS DATE: [illegible]

YOUR P. O. No: [illegible], Swisher C-2-5 FILE No:

MANUFACTURED BY: SECTION No.

PRIME CONTRACTOR: MATERIAL: Electro deposited nickel specimens

SUBCONTRACTOR: ATTN: Mr. F. D. McCary SPECIFICATION:

PHYSICAL PROPERTIES

HEAT NUMBER	ACTUAL SIZE	ACTUAL AREA	YIELD POINT: ACTUAL LOAD IN LBS.	YIELD POINT: POUNDS PER SQ. IN.	TENSILE STRENGTH: ACTUAL LOAD IN LBS.	TENSILE STRENGTH: POUNDS PER SQ. IN	ELONGATION IN 2 IN.	ELONGATION PER CENT	REDUCED DIMENSION	REDUCTION OF AREA PER CENT	CODE	LAB NO.
ROOM TEMPERATURE TENSILE TESTS												
F-26												
1	.497 / .0082	.004075	358	90300	540	133000	0.08	4				42-129P
2	.497 / .0082	.004075	355	87100	542	133000	[illegible]	5				
3	.497 / .0083	.004125	355	86100	544	132000	[illegible]	5				
F-28												
1	.496 / .0041	.002034	118	58000	171	84100	0.09	5				
2	.496 / .0040	.001984	114.4	57700	165.4	83400	0.09	5				
3	.497 / .0041	.002038	112.8	55300	170.8	83800	0.09	5				
MAXIMUM REQUIREMENTS												
MINIMUM REQUIREMENTS												

YIELD STRENGTH BY EXTENSOMETER AT IN 2".
Code: 0.2% Offset
(F) indicates flaw
(G) " broke outside gauge mark
(g) " broke at gauge mark

WITNESSED BY:
NAVY INSPECTOR
ARMY INSPECTOR

2100-IR-1

RESPECTFULLY SUBMITTED
J. E. Clark
METAL CONTROL LABORATORIES
CHEMISTS - METALLURGISTS - ENGINEERS - INSPECTORS

DATA SHEET

Date 6 April 1962

Sample F-26-1

Test No.

Area 0.004075

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress/psi	Strain/in.	$E \times 10^6$	
25	6,140	.00020	30.7	
50	12,300	.00042	29.2	
75	18,400	.00064	28.8	
100	24,500	.00085	28.8	
125	30,700	.00110	27.4	
150	36,800	.00138	26.6	
175	42,900	.00166	25.8	
200	49,100	.00198	24.8	
225	55,200	.00232	23.8	
250	61,400	.00271	22.6	
275	67,500	.00317	21.2	
300	73,600	.00368	20.0	
325	79,900	.00429	18.6	
350	86,000	.00498	17.3	
375	92,100	.00577	16.0	
400				
425				
450				
475				
500				
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

EOS FORM 247 (REV.)

DATA SHEET

Page 1 of 1

Date 6 April 1962

Sample F-26-2

Test No.

Area .004125

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress/psi	Strain/in.	E x 10^6	
25	6,230	.00024	25.9	
50	12,450	.00041	30.4	
75	18,680	.00069	28.1	
100	24,900	.00092	27.1	
125	31,200	.00118	26.4	
150	37,400	.00148	25.2	
175	43,600	.00178	24.5	
200	44,800	.00212	23.4	
225	56,100	.00247	22.7	
250	62,300	.00287	21.7	
275	68,500	.00384	20.5	
300	74,800	.00385	19.4	
325	80,900	.00444	18.2	
350	87,100	.00513	17.0	
375	93,400	.00594	15.7	
400				
425				
450				
475				
500				
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

EO FO 247 (RV)

DATA SHEET

Page 1 of 1

Date 6 April 1962

Sample F-26-3

Area .004125

Test No.

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress/psi	Strain in.	$E \times 10^6$	
25	6,230	.00020	31.2	
50	12,450	.00041	30.4	
75	18,650	.00064	29.2	
100	24,900	.00088	28.3	
125	31,100	.00113	27.6	
150	37,400	.00140	26.6	
175	43,600	.00170	25.6	
200	49,800	.00202	24.7	
225	56,100	.00239	23.4	
250	62,300	.00278	22.4	
275	68,500	.00323	21.2	
300	74,700	.00375	19.9	
325	81,000	.00435	18.6	
350	87,200	.00504	17.3	
375	93,400	.00600	15.5	
400				
425				
450				
475				
500				
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

EOS FORM 247 (REV.)

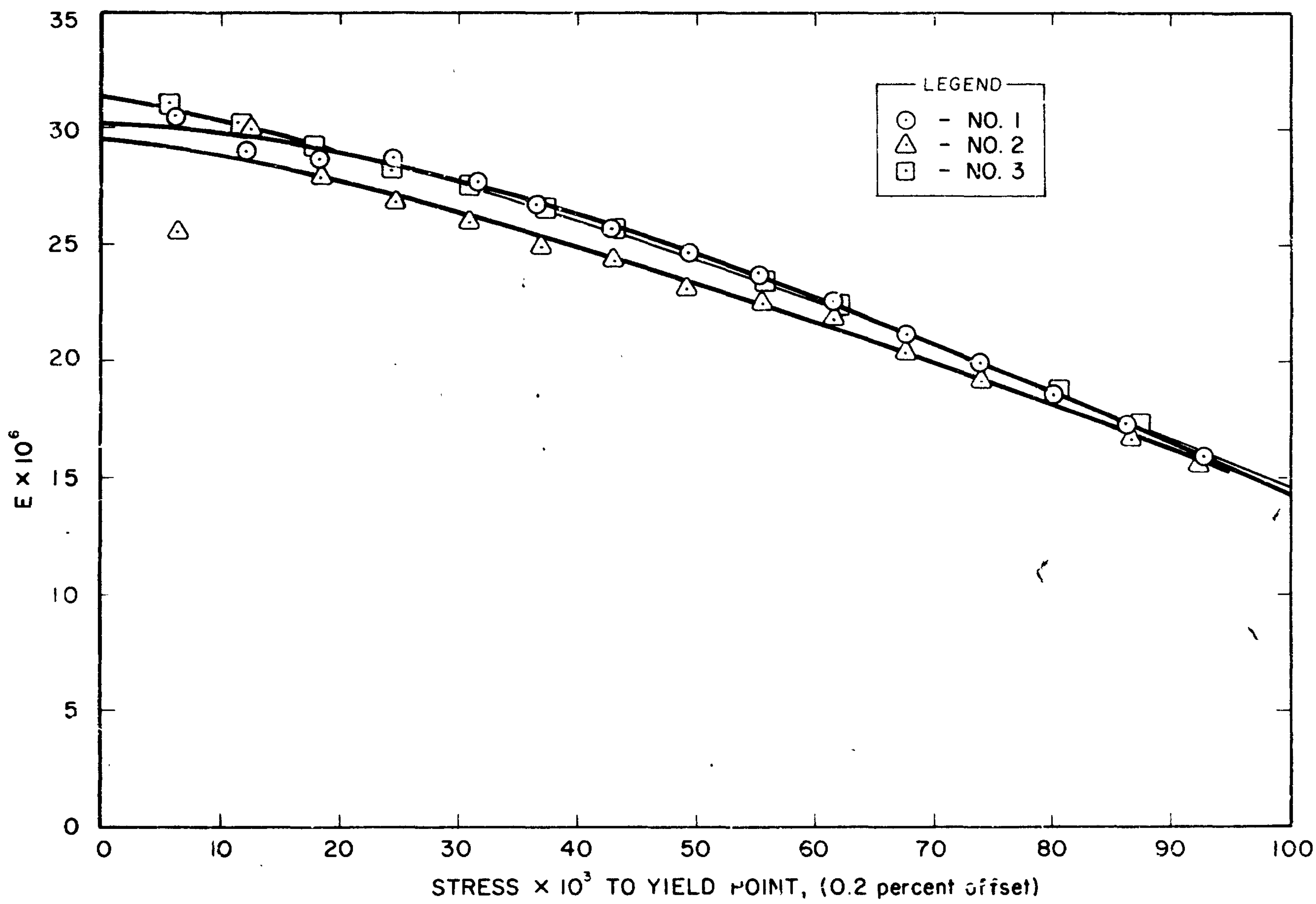

FIG. 3-18 SAMPLE F-26-1

DATA SHEET

Page 1 of 1

Date 6 April 1962

Sample F-28-1

Area 0.002034

Test No.

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress/psi	Strain/in.	$E \times 10^6$	
25	12,300	.00047	26.2	
50	24,600	.00114	21.6	
75	36,900	.00190	19.4	
100	49,300	.00319	15.4	
125	61,700	.00549	11.2	
150				
175				
200				
225				
250				
275				
300				
325				
350				
375				
400				
425				
450				
475				
500				
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

2100-IR-1

EOS FORM 247 (REV.)

DATA SHEET

Date 6 April 1962

Sample F-28-2

Test No

Area 0.001984

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress psi	Strain in/in	$E \times 10^6$	
25				
50	25,200	.00073	34.6	
75	37,800	.00147	25.7	
100	50,400	.00280	18.0	
125	63,000	.00532	11.8	
150				
175				
200				
225				
250				
275				
300				
325				
350				
375				
400				
425				
450				
475				
500				
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

2100-IR-1

EOS FORM 247 (REV.)

DATA SHEET

Date 6 April 1962

Sample F-28-3

Test No.

Area 0.002038

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress psi	Strain [illegible]	E x 10^6	
25	12,250	.00036	34.1	
50	24,500	.00088	27.8	
75	36,800	.00165	22.3	
100	49,000	.00297	16.5	
125	61,400	.00551	11.1	
150				
175				
200				
225				
250				
275				
300				
325				
350				
375				
400				
425				
450				
475				
500				
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

EOS FORM 247 (REV.)

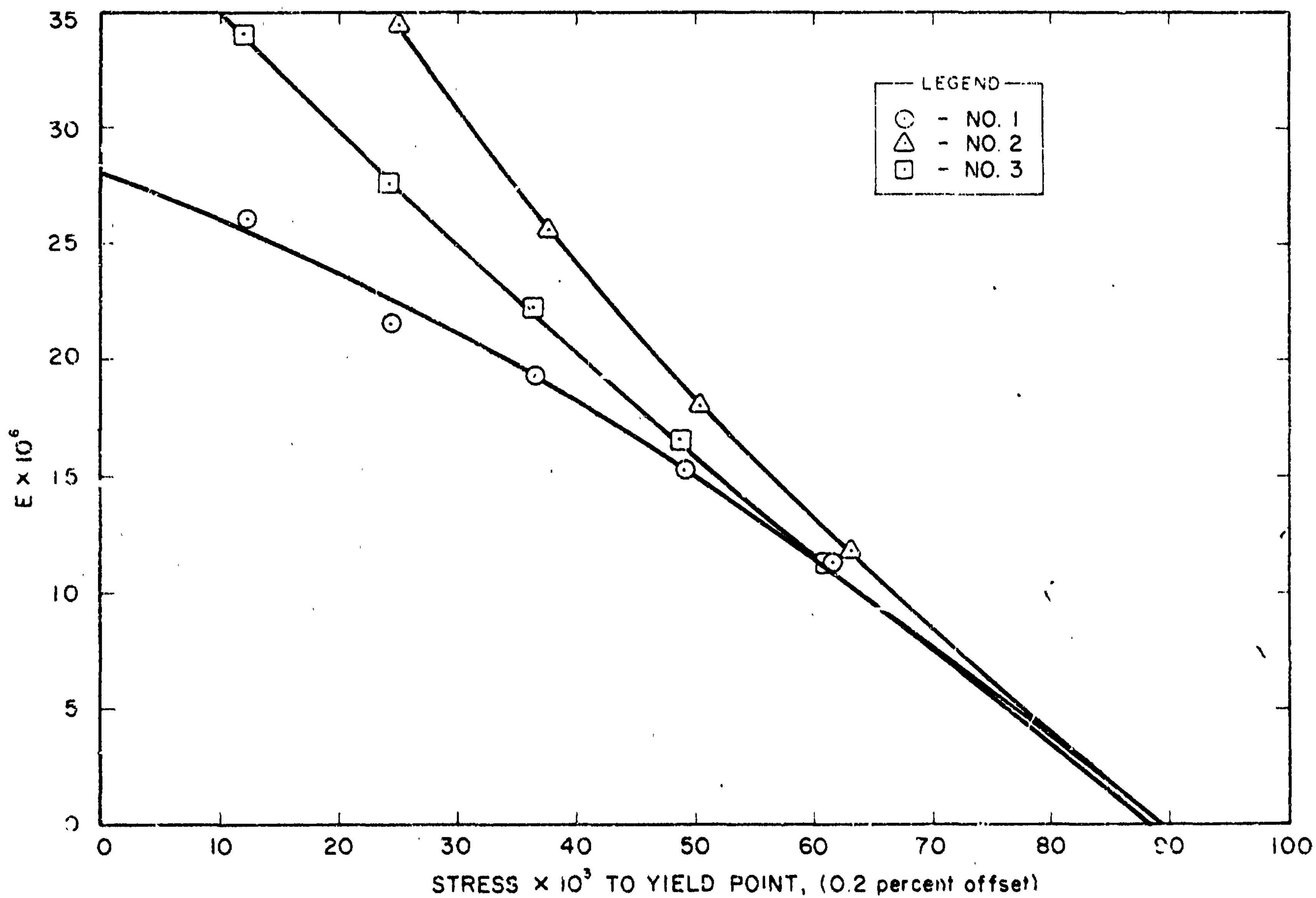

FIG. 3-19 SAMPLE F-28-1

LABORATORIES · CHEMICAL · PHYSICAL · METALLURGICAL · QUANTOMETRIC · NON DESTRUCTIVE · INSPECTION · RESEARCH

METAL CONTROL LABORATORIES

INCORPORATED
2735 EAST SLAUSON AVENUE
HUNTINGTON PARK, CALIF.
LUdlow 8-4161

CERTIFIED REPORT OF PHYSICAL TEST

[illegible]	[illegible]	DATE	[illegible]
YOUR P. O. No.	[illegible]	FILE No.	
MANUFACTURED BY		SECTION No.	
PRIME CONTRACTOR		MATERIAL	[illegible]
SUBCONTRACTOR		SPECIFICATION	---

[illegible]

PHYSICAL PROPERTIES

HEAT NUMBER	ACTUAL SIZE	ACTUAL AREA	YIELD POINT: ACTUAL LOAD IN LBS.	YIELD POINT: POUNDS PER SQ. IN.	TENSILE STRENGTH: ACTUAL LOAD IN LBS.	TENSILE STRENGTH: POUNDS PER SQ. IN.	ELONGATION IN 2 IN.	ELONGATION PER CENT	REDUCED DIMENSION	REDUCTION OF AREA PER CENT	CODE	LAB NO.
[illegible]												
[illegible]												[illegible]
1	.5[illegible] / .0075	.00[illegible]	[illegible]	75[illegible]	45[illegible]	[illegible]	[illegible]	7[illegible]				
2	.500 / .0078	.00380	[illegible]	79000	4[illegible]	[illegible]	[illegible]	[illegible]				
3	.500 / .0078	.00[illegible]	[illegible]	75000	4[illegible]	[illegible]	0.16	8.[illegible]				
[illegible]-30												
1	.488 / .0095	.00465	----*	----	[illegible]	370[illegible]	0	0			G	
2	.495 / .0097	.00[illegible]	----*	----	46	10000	0	0			G	
[illegible]-32												
1	[illegible] / .0037	.00[illegible]37	[illegible]	[illegible]	[illegible]	1[illegible]	0.1[illegible]	[illegible]				
2	[illegible] / .0035	.00[illegible]	[illegible]	[illegible]	[illegible]	1[illegible]	[illegible]	[illegible]				
3	[illegible] / .0034	.00[illegible]72	4[illegible]	[illegible]	70	1[illegible]	0.1[illegible]	[illegible]				
MAXIMUM REQUIREMENTS												
MINIMUM REQUIREMENTS				---		---		---				

YIELD STRENGTH BY EXTENSOMETER AT [illegible] IN 2", * [illegible] Offset [illegible]

Code:
(F) indicates flaw
(G) " broke outside gauge mark
(a) " broke at gauge mark

WITNESSED BY:
NAVY INSPECTOR
ARMY INSPECTOR

2100-IR-1

RESPECTFULLY SUBMITTED

[illegible]

METAL CONTROL LABORATORIES
CHEMISTS · METALLURGISTS · ENGINEERS · INSPECTORS

DATA SHEET

Page 1 of 1

Date 9 April 1962

Sample F-29-1

Area .00375

Test No. ______

By Metal Control Laboratories, Inc

E O S ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Str[illegible] - psi	Stra[illegible]	E - Y.[illegible]	
25	6,670	.00025	26.6	
50	13,300	.00050	26.7	
75	20,000	.00077	26.0	
100	26,700	.00104	25.6	
125	33,400	.00135	24.6	
150	40,100	.00168	23.8	
175	46,600	.00207	22.6	
200	53,400	.00250	21.3	
225	60,000	.00301	19.9	
250	66,700	.00361	13.5	
275	73,400	.00433	16.9	
300	80,200	.00518	15.5	
325				
350				
375				
400				
425				
450				
475				
500				
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

2100-IR-1

EOS FORM 247 (REV.)

DATA SHEET

Date 9 April 1962

Sample F-29-2

Area 0.00380

Test No.

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress psi	Strain, in.	E x 10^6	
25	6,590	.00012	54.9	
50	13,160	.00047	28.0	
75	19,700	.00074	26.6	
100	26,300	.00102	25.8	
125	32,900	.00134	24.6	
150	39,500	.00168	23.5	
175	46,100	.00206	22.3	
200	52,600	.00248	21.2	
225	59,300	.00296	20.0	
250	65,700	.00353	18.6	
275	72,400	.00419	17.3	
300	78,900	.00499	15.8	
325	85,500	.00597	14.3	
350				
375				
400				
425				
450				
475				
500				
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

FORM 247 (REV.)

DATA SHEET

Date 9 April 1962

Sample F-29-3

Area .00390

Test No.

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress/psi	Strain/in.	E x 10^{6}	
25	6,4100	.00027	23.8	
50	12,800	.00054	23.8	
75	19,200	.00080	24.0	
100	25,600	.00107	24.0	
125	32,100	.00137	23.4	
150	38,500	.00171	22.5	
175	44,900	.00201	22.3	
200	51,300	.00252	20.3	
225	57,300	.00303	19.1	
250	64,200	.00359	17.9	
275	70,600	.00428	16.5	
300	77,000	.00510	15.1	
325	83,500	.00588	14.2	
350				
375				
400				
425				
450				
475				
500				
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

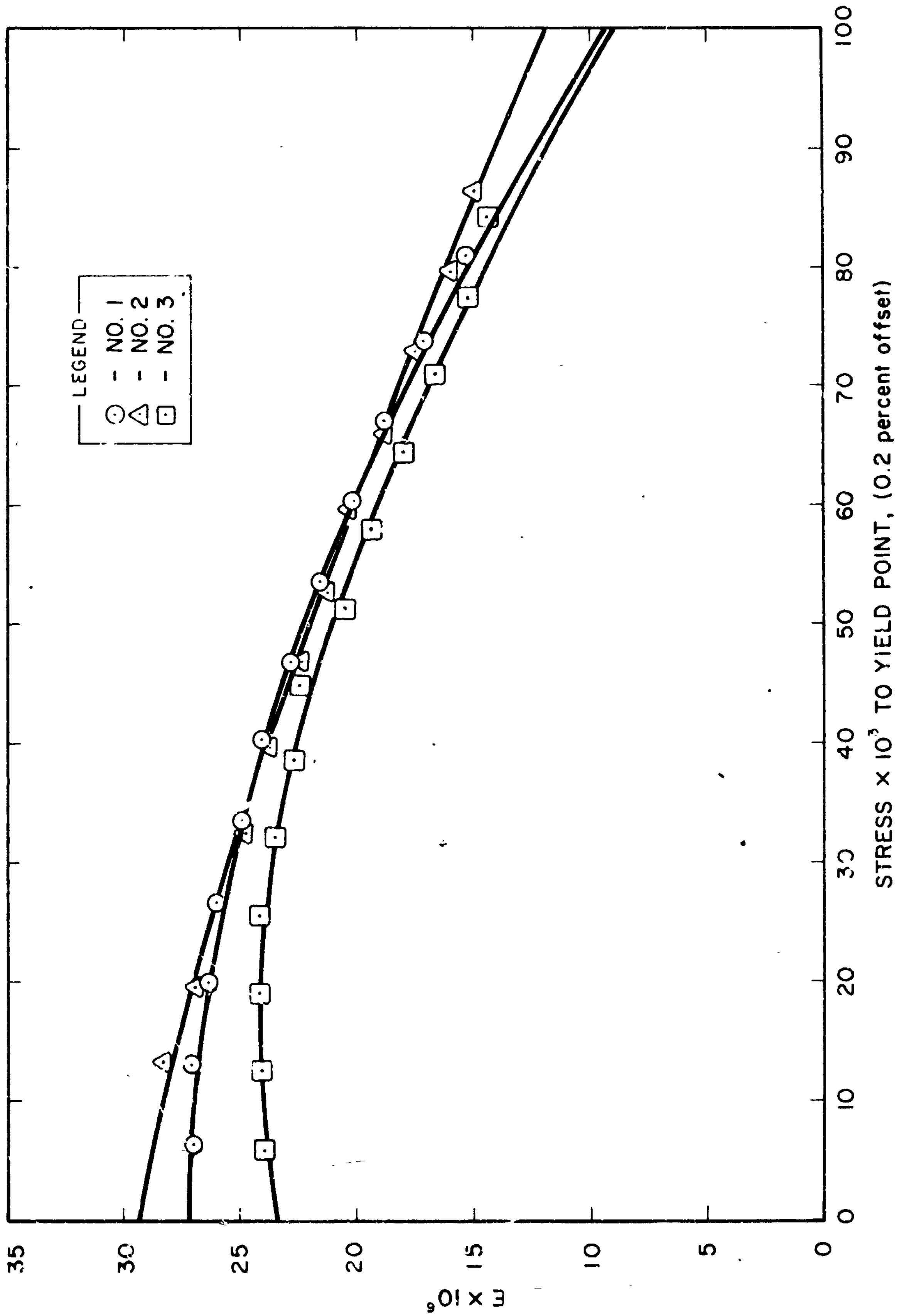

FIG. 3-20 SAMPLE F-29-1

DATA SHEET

Page 1 of 1

Date 9 April 1962

Sample F-32-1

Area .00487

Test No.

By Metal Control Laboratories, Inc.

EOS ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress/psi	Strain/in.	$E \times 10^6$	
25	5,140	.00017	30.2	
50	10,250	.00038	27.0	
75	15,400	.00063	24.4	
100	20,500	.00087	23.6	
125	25,600	.00112	22.9	
150	30,800	.00137	22.4	
175	36,000	.00161	22.3	
200	41,100	.00187	21.9	
225	46,200	.00215	21.5	
250	51,400	.00243	21.1	
275	56,500	.00264	21.4	
300	61,600	.00305	20.2	
325	66,700	.00338	19.7	
350	71,800	.00375	19.2	
375	77,000	.00418	18.4	
400	82,100	.00466	17.6	
425	87,300	.00516	16.9	
450	92,500	.00572	16.1	
475	97,500	.00642	15.2	
500	102,600	.00724	14.2	
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

EOS FORM 247 (REV)

DATA SHEET

Page 1 of 1

Date 9 April 1962

Sample F-32-2

Test No.

Area 0.00476

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress/psi	Strain/in.	E x Y10^6	
25				
50	10,500	.00051	20.6	
75	15,750	.00078	20.2	
100	21,000	.00102	20.6	
125	26,200	.00128	20.5	
150	31,500	.00156	20.2	
175	36,800	.00181	20.3	
200	42,000	.00209	20.0	
225	47,300	.00237	19.9	
250	52,200	.00266	19.7	
275	57,800	.00292	19.8	
300	63,000	.00325	19.4	
325	68,300	.00358	19.1	
350	73,500	.00396	18.5	
375	78,800	.00437	18.0	
400	84,000	.00482	17.4	
425	89,300	.00531	16.8	
450	94,500	.00587	16.1	
475	99,700	.00647	15.4	
500	105,000	.00718	14.6	
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

EOS FORM 247 (REV.)

DATA SHEET

Date 9 April 1962

Sample F-32-3

Area 0.00472

Test No.

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress/psi	Strain/in.	E x10[6]	
25				
50	10,600	.00040	26.5	
75	15,900	.00057	27.9	
100	21,200	.00081	26.1	
125	26,400	.00099	26.8	
150	31,800	.00122	26.0	
175	37,100	.00146	25.4	
200	42,400	.00170	24.9	
225	47,700	.00197	24.2	
250	53,000	.00223	23.8	
275	58,300	.00251	23.2	
300	63,600	.00285	22.3	
325	68,900	.00320	21.5	
350	74,000	.00359	20.6	
375	79,500	.00403	19.7	
400	84,700	.00449	18.9	
425	90,000	.00499	18.0	
450	95,400	.00558	17.1	
475	100,600	.00621	16.4	
500				
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

EOS FORM 247 (REV.)

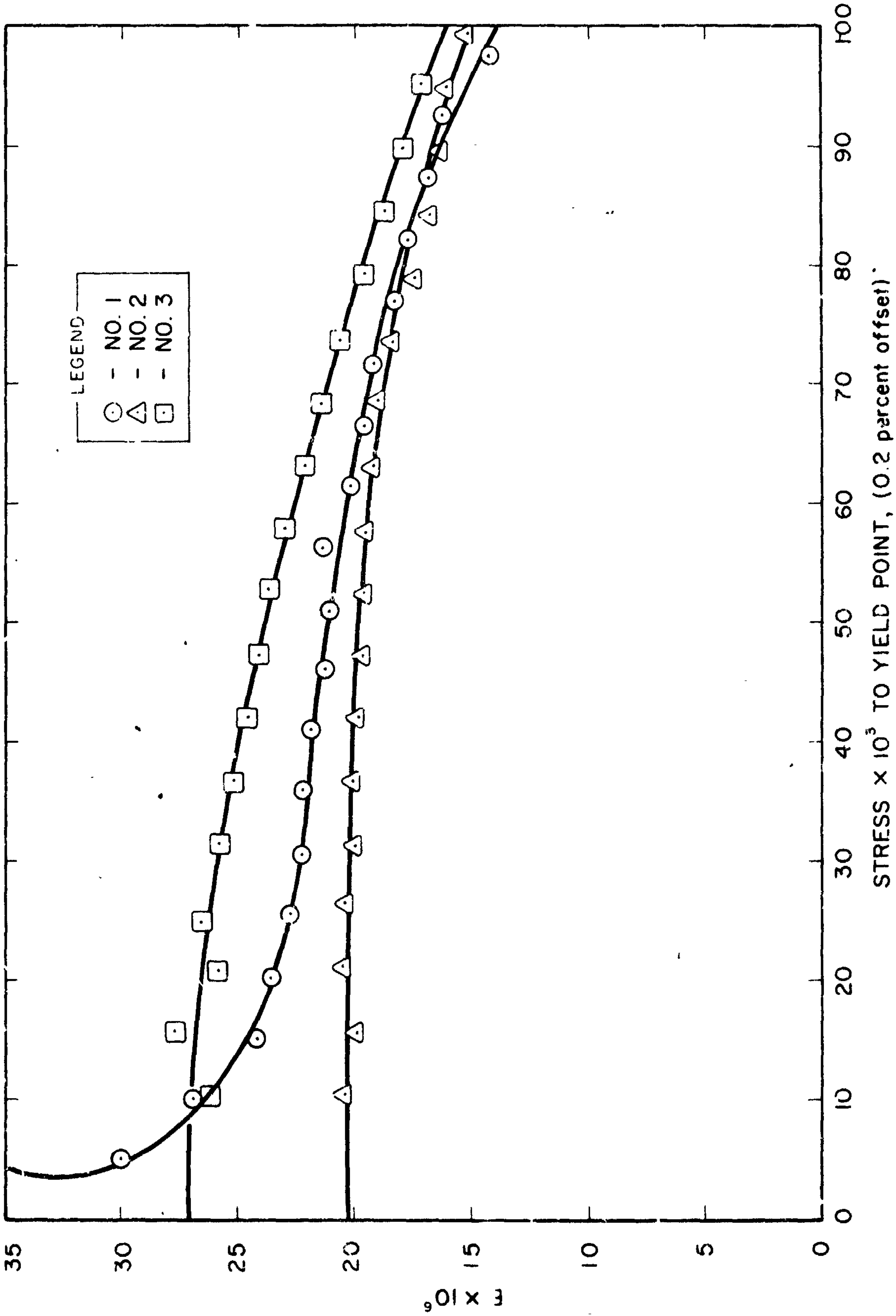

FIG. 3-21 SAMPLE F-32-1

LABORATORIES CHEMICAL - PHYSICAL - METALLURGICAL - QUANTOMETRIC - NON DESTRUCTIVE - INSPECTION - RESEARCH

METAL CONTROL LABORATORIES

INCORPORATED
2735 EAST SLAUSON AVENUE
HUNTINGTON PARK, CALIF.
LUdlow 8-4161

CERTIFIED REPORT OF PHYSICAL TEST

FOR ACCOUNT OF	[illegible], INC.	DATE	[illegible]-62
YOUR P.O. No.	18523, Shipper B-353	FILE No.	
MANUFACTURED BY:		SECTION No.	
PRIME CONTRACTOR-		MATERIAL	Nickel Specimens
SUBCONTRACTOR:		SPECIFICATION	----

Attn: Mr. [illegible] B. McCrary

PHYSICAL PROPERTIES

		YIELD POINT:			TENSILE STRENGTH:							
HEAT NUMBER	ACTUAL SIZE	ACTUAL AREA	ACTUAL LOAD IN LBS.	POUNDS PER SQ. IN.	ACTUAL LOAD IN LBS.	POUNDS PER SQ. IN.	ELONGATION IN 2 IN.	ELONGATION PER CENT	REDUCED DIMENSION	REDUCTION OF AREA PER CENT	CODE	LAB NO.
ROOM TEMPERATURE TENSILE TEST												
F-33												42-[illegible]
1	.501 .0080	.00401	325	81000	5[illegible]6	130000	0.18	9.0			g	
2	.500 .0083	.00415	320	77000	434	120000	0.18	9.0			g	
3	.500 .0091	.00455	322	71000	500	110000	0.16	8.0				
F-36												
1	.500 .0051	.00255	203	80000	302	120000	0.12	6.0			g	
2	.500 .0051	.00255	208	82000	310	120000	0.11	5.5				
3	.501 .0051	.00256	212	83000	315	120000	0.08	4				
F-37												
1	.500 .0054	.00270	200	74000	302	110000	0.11	5.5				
2	.502 .0056	.00281	202	72000	310	110000	0.10	5.0			g	
3	.498 .0058	.00289	207	72000	316	110000	0.15	7.5				
MAXIMUM REQUIREMENTS												
MINIMUM REQUIREMENTS				---		---		---				

YIELD STRENGTH BY EXTENSOMETER AT 0.2% IN 2". Offset

Code:
(F) indicates flaw
(O) " breaks outside gauge mark
(g) " breaks at gauge mark

WITNESSED BY:
☐ NAVY INSPECTOR
☐ ARMY INSPECTOR
☐ 2100-IR-1

RESPECTFULLY SUBMITTED

Paul J. [illegible]

METAL CONTROL LABORATORIES
CHEMISTS - METALLURGISTS - ENGINEERS - INSPECTORS

DATA SHEET

Page 1 of 1

Date 9 April 1962

Sample F-33-1

Area 0.00401

Test No.

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress/psi	Strain/in.	E x 10^6	
25				
50	12,500	.00044	28.4	
75				
100	25,000	.00088	28.4	
125				
150	37,400	.00142	26.4	
175				
200	50,000	.00207	24.1	
225				
250	62,400	.00291	21.4	
275				
300	74,800	.00405	18.4	
325				
350	87,300	.00571	15.6	
375				
400				
425				
450				
475				
500				
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

DATA SHEET

Page 1 of 1

Date 9 April 1962

Sample F-33-2

Test No.

Area 0.00415

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress/psi	Strain/in.	E x Y10[6]	
25				
50	12,050	.00045	26.8	
75				
100	24,100	.00092	26.2	
125				
150	36,100	.00146	24.7	
175				
200	48,200	.00216	22.3	
225				
250	60,300	.00309	19.5	
275				
300	72,400	.00431	16.8	
325				
350	84,400	.00613	13.8	
375				
400				
425				
450				
475				
500				
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

DATA SHEET

Page 1 of 1

Date 9 April 1962

Sample F-33-3

Test No.

Area 0.00455

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress/psi	Strain/in.	E x Y10[6]	
25				
50	11,000	.00041	26.8	
75				
100	22,000	.00089	24.8	
125				
150	33,000	.00145	22.7	
175				
200	44,000	.00212	20.8	
225				
250	55,000	.00300	18.3	
275				
300	66,000	.00418	15.8	
325				
350	77,000	.00593	13.0	
375				
400				
425				
450				
475				
500				
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

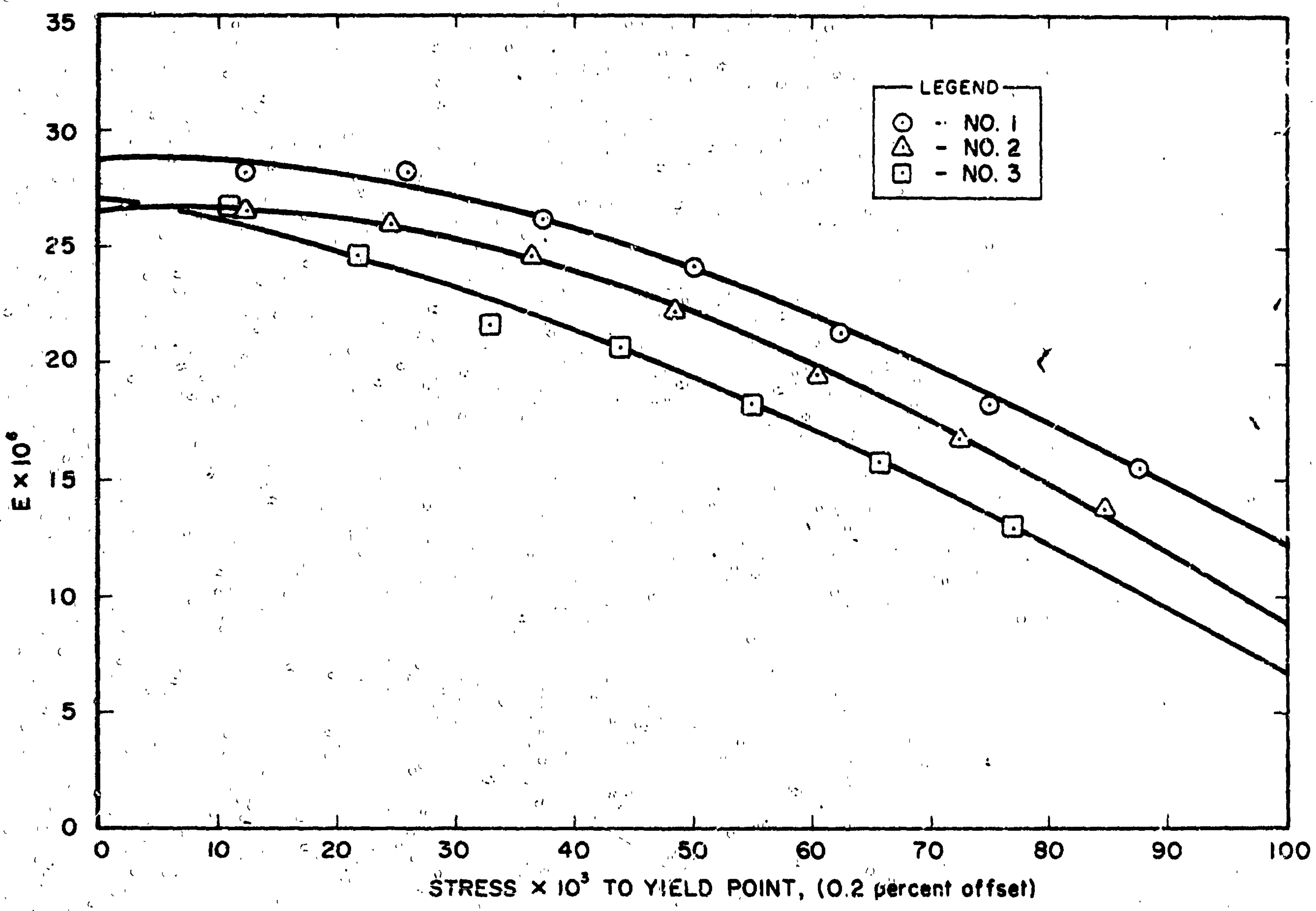

FIG. 3-22 SAMPLE F-33-1

DATA SHEET

Sample F-36-1

Area 0.00255

Date 9 April 1962

Test No.

By Metal Control Laboratories, Inc.

W.A. 2100

ELECTRO-OPTICAL SYSTEMS, INC.

Load/lbs	Stress/psi	Strain/in.	E x Y10^6	
25	4,800	.00038	25.8	
50	19,600	.00077	25.5	
75	29,400	.00118	24.9	
100	39,200	.00163	24.0	
125	49,000	.00219	22.4	
150	58,900	.00287	20.5	
175	68,600	.00378	18.4	
200	78,500	.00496	15.8	
225	88,300	.00660	13.4	
250				
275				
300				
325				
350				
375				
400				
425				
450				
475				
500				
525				
550				
575				
600				
625				
650				
675				
700				
725				
750				
775				
800				

DATA SHEET

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Date 9 April 1962

Sample F-36-2

Test No.

Area 0.00255

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress/psi	Strain/in.	E x 10^6	
25	9,800	.00043	22.8	
50	19,600	.00080	24.5	
75	29,400	.00120	24.5	
100	39,200	.00169	23.2	
125	49,000	.00223	22.0	
150	58,900	.00284	20.4	
175	68,600	.00372	18.5	
200	78,500	.00482	16.2	
225	88,300	.00628	14.1	
250				
275				
300				
325				
350				
375				
400				
425				
450				
475				
500				
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550				
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775				
800				

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Date 9 April 1962

Sample F-36-3

Test No.

Area 0.00256

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress/psi	Strain/in.	E x Y10^6	
25	9,760	.00040	24.4	
50	19,500	.000[illegible]	25.4	
75	29,300	.00118	24.8	
100	39,100	.00165	23.6	
125	48,900	.00218	22.4	
150	58,600	.00282	20.8	
175	68,400	.00363	18.8	
200	78,100	.00464	16.9	
225	88,000	.00602	14.6	
250				
275				
300				
325				
350				
375				
400				
425				
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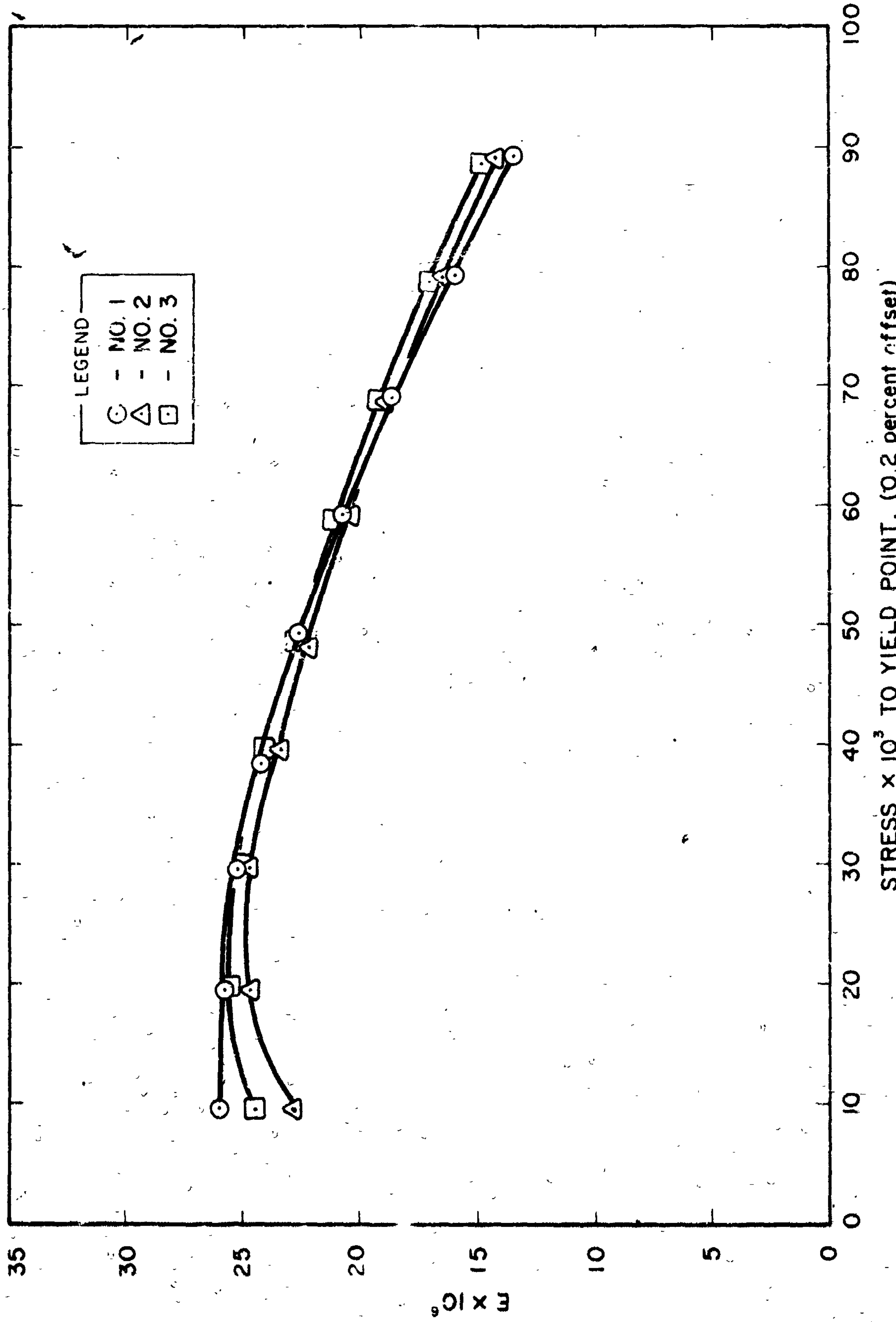

FIG. 3-23 SAMPLE F-36-1

DATA SHEET

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Date 9 April 1962

Sample F-37-1

Test No.

Area .00270

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress/psi	Strain/in.	E x Y10^{6}	
25	9,250	.00040	23.1	
50	18,500	.00077	24.0	
75	27,800	.00120	23.2	
100	37,100	.00168	22.0	
125	46,300	.00228	20.3	
150	55,500	.00299	18.5	
175	65,000	.00387	16.7	
200	74,000	.00504	14.7	
225	83,400	.00682	12.2	
250				
275				
300				
325				
350				
375				
400				
425				
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Date	9 April 1962
Test No.	
By	Metal Control Laboratories, Inc.
W.A.	2100

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Sample P-37-2

Area 0.00281

ELECTRO-OPTICAL SYSTEMS, INC.

Load/lbs	Stress/psi	Strain/in.	E x Y10[6]	
25	8,900	.00036	24.7	
50	17,800	.00072	24.8	
75	26,700	.00110	24.2	
100	35,600	.00157	22.6	
125	44,500	.00211	21.0	
150	53,400	.00277	19.7	
175	62,300	.00367	17.0	
200	71,200	.00444	16.0	
225	80,200	.00638	12.5	
250				
275				
300				
325				
350				
375				
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Date 9 April 1962

Sample F-37-3

Test No.

Area 0.00289

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress/psi	Strain/in.	E x Y10[6]	
25	8,650	.00033	26.2	
50	17,300	.00068	25.4	
75	25,900	.00104	25.0	
100	34,600	.00147	23.6	
125	43,300	.00199	21.7	
150	52,000	.00263	19.7	
175	60,500	.00344	17.6	
200	69,200	.00446	15.5	
225	78,000	.00594	13.1	
250				
275				
300				
325				
350				
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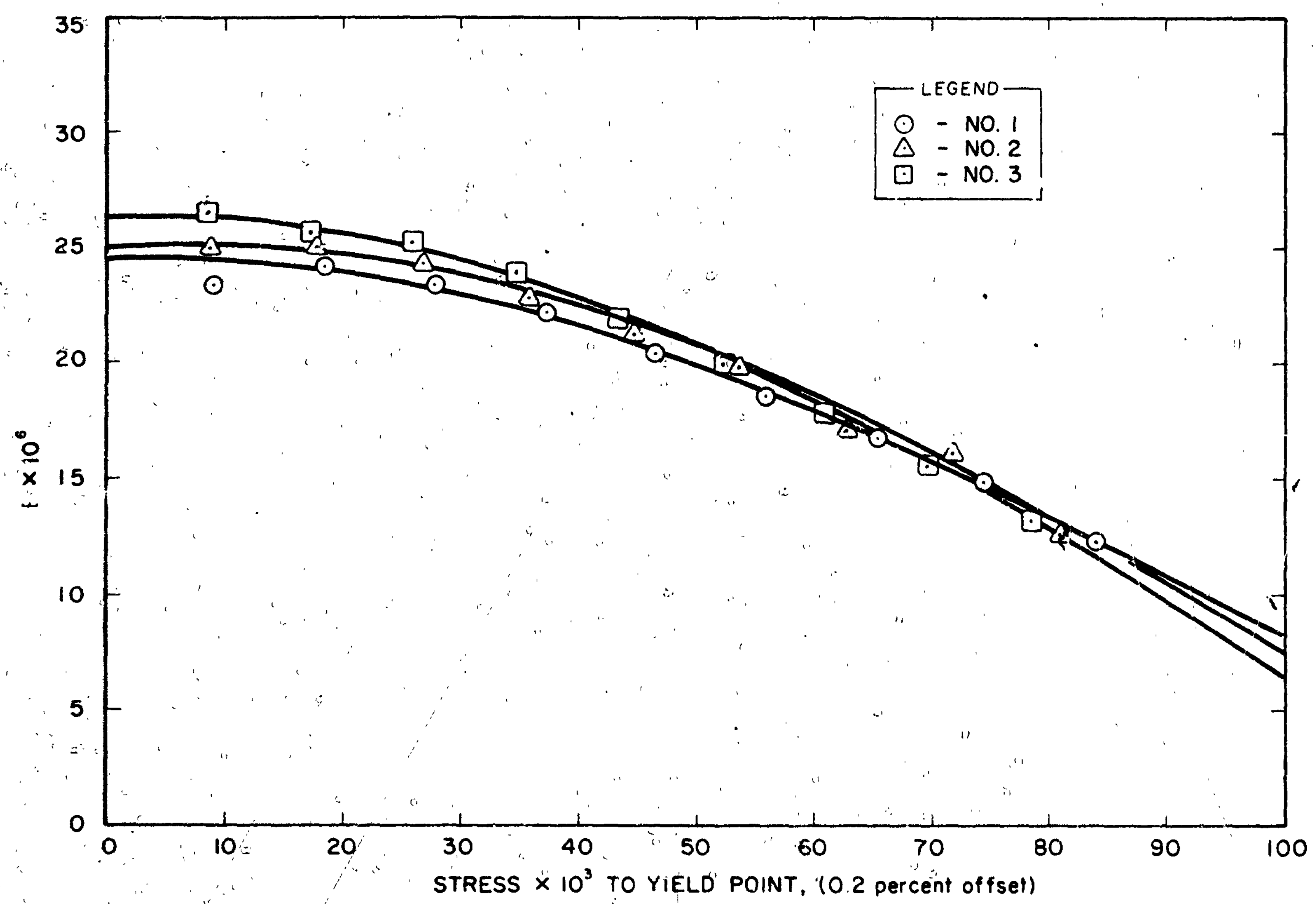

FIG. 3-24 SAMPLE F-37-

METAL CONTROL LABORATORIES

INCORPORATED
2735 EAST SLAUSON AVENUE
HUNTINGTON PARK, CALIF.
LUDLOW 8-4161

CERTIFIED REPORT OF PHYSICAL TEST

FOR ACCOUNT OF: ELECTRO-OPTICAL SYSTEMS, INC. DATE 1-9-62

YOUR P O No. 16829, Shipper B-339 FILE No

MANUFACTURED BY: SECTION No.

PRIME CONTRACTOR: MATERIAL Nickel Specimens

SUBCONTRACTOR: SPECIFICATION ----

PHYSICAL PROPERTIES

HEAT NUMBER	ACTUAL SIZE	ACTUAL AREA	YIELD POINT: ACTUAL LOAD IN LBS.	POUNDS PER SQ. IN.	TENSILE STRENGTH: ACTUAL LOAD IN LBS.	POUNDS PER SQ. IN.	ELONGATION IN 2 IN.	ELONGATION PER CENT	REDUCED DIMENSION	REDUCTION OF AREA PER CENT	CODE	LAB NO.
ROOM TEMPERATURE TENSILE TEST												
F-39												12-411P
1	.499 / .0092	.00459	268	58000	392	85000	0.14	7.0			g	
2	.501 / .0094	.00471	282	60000	393	83000	0.12	6.0			g	
3	.500 / .0095	.00475	264	56000	392	83000	0.12	6.0			g	
MAXIMUM REQUIREMENTS												
MINIMUM REQUIREMENTS				---		---		---				

YIELD STRENGTH BY EXTENSOMETER AT 0.2% Offset IN 2".

Code:
( ) indicates flaw
( ) " broke outside gauge mark
( ) " broke at gauge mark

WITNESSED BY:
☐ NAVY INSPECTOR
☐ ARMY-INSPECTOR
☐

2100-IR-1

RESPECTFULLY SUBMITTED

METAL CONTROL LABORATORIES
CHEMISTS - METALLURGISTS - ENGINEERS - INSPECTORS

Date 9 April 1962

DATA SHEET

Sample F-39-1

Area 0.00459

Test No.

By Metal Control Laboratories, Inc.

EOS ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress/psi	Strain/in.	$E \times Y10^6$	
25	5,450	.00025	21.8	
50	10,900	.00047	23.2	
75	16,350	.00070	23.4	
100	21,800	.00094	23.2	
125	27,200	.00125	21.8	
150	32,700	.00159	20.6	
175	38,200	.00200	19.1	
200	43,600	.00250	17.4	
225	49,000	.00308	15.9	
250	54,500	.00380	14.3	
275	60,000	.00474	12.6	
300				
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350				
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Date 9 April 1962

Sample F-39-2

Area 0.00471

Test No

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress/psi	Strain/in.	E x Y10[6]	
25	5,300	.00020	26.5	
50	10,600	.00040	26.6	
75	15,900	.00060	26.6	
100	21,200	.00081	26.2	
125	26,500	.00108	24.6	
150	31,800	.00137	23.2	
175	37,200	.00170	21.8	
200	42,400	.00210	21.1	
225	47,800	.00260	18.4	
250	53,000	.00324	16.4	
275	58,400	.00407	14.3	
300	63,700	.00504	12.6	
325				
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DATA SHEET

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Date 9 April 1962

Sample F-39-3

Area 0.00475

Test No.

By Metal Control Laboratories, Inc.

ELECTRO-OPTICAL SYSTEMS, INC.

W.A. 2100

Load/lbs	Stress/psi	Strain/in.	E x Y10^6	
25	5,270	.00021	25.1	
50	10,520	.00042	25.1	
75	15,800	.00065	24.3	
100	21,050	.00091	23.2	
125	26,400	.00119	22.1	
150	31,600	.00151	20.9	
175	36,800	.00191	19.3	
200	42,200	.00239	17.6	
225	47,400	.00300	15.8	
250	52,600	.00382	13.8	
275	58,000	.00495	11.7	
300				
325				
350				
375				
400				
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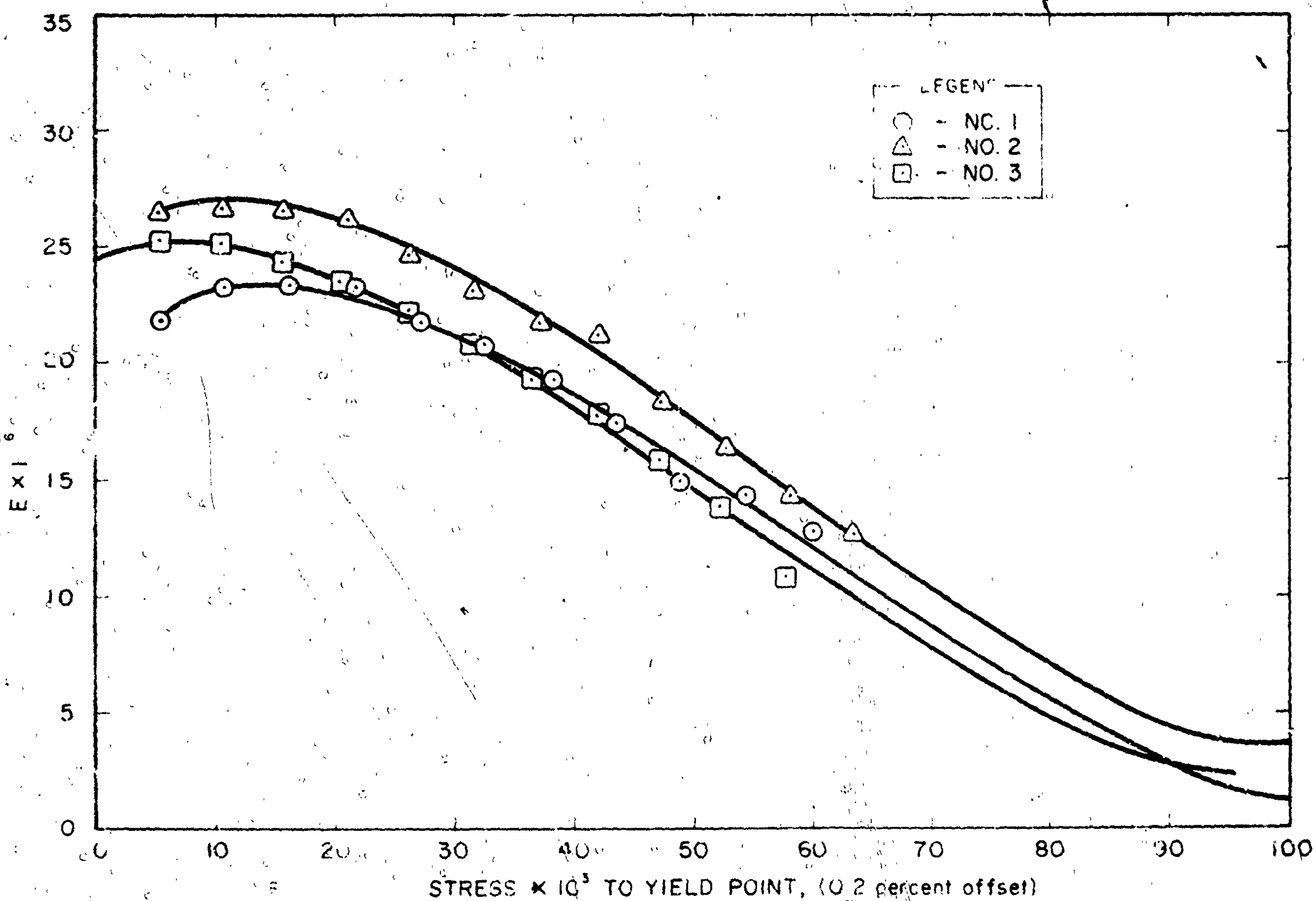

FIG. 3-25 SAMPLE F-39-1

4. ADVANCED COATING STUDIES

High reflectivity coatings that are compatible with electroformed structures and exhibit a high degree of resistance to degradation from environmental conditions encountered during processing, storage, launch and space conditions are of prime concern to this program.

4.1 Small-Scale Studies

A number of studies have been initiated and are continuing, which will provide a better understanding of the conditions or processes that are required to produce a durable, highly reflective surface on electroformed concentrators.

4.1.1 Effects of Master and Substrate Materials

In order to determine the possible effect of the master or substrate materials on ultimate reflectivity, a number of sample reflective skins were plated using various structural materials. Although the quality of the master is reproduced very accurately in the electroformed replica, the materials employed in the master itself have no ultimate effect on the reflectivity or durability of the resultant reflective surface. The reflectivity of the master surface, whether it is metal, plastic, or glass, will be faithfully reproduced in a replica mirror. In the case of nonconductive masters such as plastic or glass, a sensitizing layer of silver, copper or other material is used prior to the electroforming process. The subsequent electroform reproduces the surface condition of this sensitizing or reflective layer. There does not appear to be any measurable difference in reflectivities obtainable associated with the different materials that have been used to date to electroform the actual reflective face. Reflectivities measured from nickel, copper, brass, and other samples that were electroformed over the same master showed identical characteristics. Replica-substrate materials or interlayers within the reflective coatings themselves do affect stability and durability, however, and this information will be discussed in the following sections.

4.1.2 Various Coatings for High Reflectivity

In order to evaluate, on a comparative basis, the various possible high reflectivity coatings, a method was devised whereby the initial surface and substrate materials could be duplicated in an accurate manner. Figure 4-1 shows the electroforming of the basic reflectivity samples. The rectangular, flat plateglass master, approximately 12 by 15 inches, provides a basis for formation of reflective skins for all electroforming materials. Electrodeposition is achieved to a thickness of approximately 0.030 inch using a chemically deposited silver sensitizing layer. Various vacuum deposited coatings have also been used as a comparison and in instances where the electroforming solutions are not compatible with chemical silver. The electroform is parted from the master and stopped off on both front and back using Kodak metal edge resist stop-off materials. Circles are then scribed through the stop-off material on the back or nonreflective side of the sample to expose the nickel. The part is then put into an etching solution and electrochemically milled to produce individual flat samples approximately two inches in diameter. This process eliminates any possibility of bending or warping due to physical machining or cutting techniques. It is necessary that the samples be flat to insure reproducible measurements on the Perkin-Elmer spectrophotometer. The process provides a relatively large number of samples that are essentially identical in characteristics of surface condition and material. These are then coated simultaneously in a vacuum-deposition system to provide nearly identical samples for future tests of reflectivity and surface degradation.

The more common combinations of high reflectivity and protective coatings have been applied to these samples. Included are unprotected silver, which results from the sensitizing process required for the electroforming operation, unprotected aluminum, the same materials being protected with an overcoat of silicon monoxide, and chromium and silicon monoxide in various combinations and thicknesses to provide adhesion and protection.

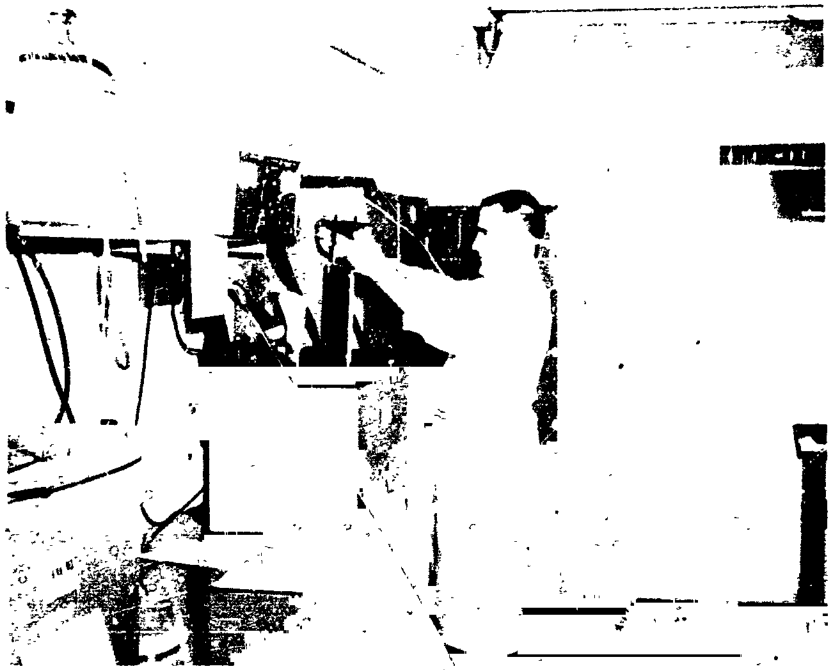

FIG. 4-1 PLATING OF REFLECTIVITY SAMPLES

FIG. 4-2 REFLECTIVITY SAMPLES - ROOFTOP EXPOSURE

Four samples of each particular coating have been prepared simultaneously. In some instances the as-formed silver surface has been left intact and the various combinations of coatings applied over the silver. Other samples have been made in which the silver has been chemically removed, leaving a reflective nickel surface on which the various combinations of coatings are subsequently deposited. Specular reflectivity measurements have been made on one of each of the four basic samples, to act as a control. The three remaining samples of each of the coatings have been, or are in the process of being, exposed to various environmental conditions.

It has been conclusively demonstrated by reflectivity and performance tests that the bright, fresh, silver surfaces provide, by a wide margin, the best reflectivity obtainable for solar concentration. Reflectivities of 94 to 96 percent are not uncommon. Unfortunately, exposed silver surfaces degrade very rapidly under normal environmental conditions with a resultant drop in reflectivity. Among the more promising coatings are vacuum-deposited aluminum (which in itself is quite durable) and combinations of vacuum-deposited aluminum overcoated with silicon monoxide, which lends a far greater protection against scratching and abrasion. Reflectivities obtainable with these coatings range from 85 to 90 percent.

Table 4-I lists the various reflectivity samples that have been prepared to date. The structural or substrate materials are listed, together with the sequence of coatings that were used. Also listed are the resultant reflectivities achieved, both on the control sample and after some preliminary environmental testing. In certain instances difficulty was achieved in reproducing reflectivity values of similar samples. This was traced to warpage of the samples, which caused errors in readout of the spectrophotometer. Those samples that were questionable have been remade and subsequent tests to substantiate or correct the prior information will be performed in the near future.

TABLE 4-1

COATINGS CHART - REFLECTIVITY SAMPLES

(11" x 16" glass master)

Reflectivity (Percent)

Sample No.	Sensitizing Layer		Plate	Chrome	SiO	Al	SiO	Silicone Oil	Before Thermal Test				After Thermal Test			
	Material	Deposition							.26μ	.55μ	1.2μ	2.00μ	.26μ	.55μ	1.2μ	2.00μ
1	Ag	Chemical	Ni	-	-	-	-	-	20.9	93.5	89.9	90.1	1.4	3.2	10.8	13.2
2	Ag	Chemical	Ni	-		-			27.7	93.3	90.7	89.9	< 1	3.3	11.8	21.7
3	Ag	Chemical	Ni	-	-	-	x	-	5.1	93.7	97.0	91.4	1.0	3.0	7.0	8.6
4	Ag	Chemical	Ni	Johnsons Metal Protector 6143 (Permacote)					~ 1	46.0	71.4	84.4	< 1	4.9	12.9	14.5
5	Ag	Chemical	Ni	-	-	x	-	-	86.8	92.1	99.2	97.5	25.5	40.9	62.8	74.1
6	Ag	Chemical	Ni	-	-	x	x	-	27.4	83.3	95.1	97.0	41.4	71.8	80.5	94.4
7	Ag	Chemical	Ni	-	x	x	x	-	5.6	35.9	99.5	97.4	13.6	85.9	89.1	96.8
8	Ag	Chemical	Ni	x	x	x	x	-	28.1	75.4	87.0	86.9	26.7	79.1	78.5	88.2
9	Ag	Chemical*	Ni	-	-	x	-	-	34.8	88.6	73.0	81.5	59.3	85.3	82.7	82.2
10	Ag	Chemical*	Ni	-	-	x	x	-	34.2	87.3	80.9	87.3	45.8	82.2	76.2	78.8
11	Ag	Chemical*	Ni	-	x	x	x	-	-	-	-	-	-	-	-	-
12	Ag	Chemical*	Ni	x	x	x	x	-	-	-	-	-	-	-	-	-
13	Ag	Vacuum	Ni	x	x	x	x	-	-	-	-	-	-	-	-	-
14	Ag	Vacuum	Ni	-	-	x	-	-	-	-	-	-	-	-	-	-
15	Ag	Chemical	Cu	-	-	-	-	-	16.2	97.1	98.0	94.2	< 1	< 1	5.7	10.0
16	Ag	Chemical*	Ni	Chrome plated			-	-	51.2	57.8	70.1	70.7	-	-	-	-
17	Ag	Chemical*	Ni	Rhodium plated			-	-	55.4	70.6	67.9	73.1	-	-	-	-
18	Ag	Chemical	Cu	x	x	x	x	-	-	-	-	-	-	-	-	-
19	Ag	Chemical	Cu	-	x	x	x	-	-	-	-	-	-	-	-	-

* Sensitizing layer removed before coating

x Coatings used

A promising overcoating for increasing total reflectivity that can be used with a variety of reflective surface materials is a multiple film of cerium dioxide and magnesium fluoride or cerium dioxide and silicon monoxide. Considerable work with these films has been accomplished by the U. S. Army Research and Development Laboratories at Fort Belvoir, Virginia. Details of this work are reported in a paper entitled "Optical Properties and Structure of Cerium Dioxide Films" by G. Haas, J. B. Ramsey, and R. Thun, Ref. Journal of the Optical Society of America, Vol. 48, No. 5, 324-327, May, 1958. These coatings show excellent abrasion and corrosion resistance, even when exposed to salt water spray, or when boiled in a 10 percent NaCl solution for several hours, according to the authors. The reflectance of the metal reflective layer can be increased over a broad spectral region by using pairs of these dielectric films with alternately low and high indexes of refraction. The films are effectively one-quarter wavelength thick and must be applied in the sequence of reflective metal, low-index film, high-index film. The visible reflectance of normal evaporated aluminum is approximately 90 percent in the visible range. The same surface, coated with the pairs of dielectric films, exhibits a maximum reflectance of 96 percent plus and at all wavelengths of the visible spectrum its reflectivity is higher than that of uncoated aluminum. Samples of these coatings will be prepared during the following phases of the reflectivity studies. Use of these coatings appears to offer a good possibility for providing high reflectivity and surface protection on electroformed metal concentrators.

One more of the promising methods of producing reflective and protective layers for electroformed concentrators is that of predepositing the coatings on the master before formation of the electroformed reflective-face skin itself. Experimental studies of this nature have been performed by G. Haas and associates at Fort Belvoir, Virginia, on small-scale samples with relatively good success. During the course of the present program at EOS, a variety of different predeposited combinations were applied to small samples prior to electroforming. In application, the glass master is first coated by the vacuum-deposition process with a parting layer such as silver or copper. Next, and in succession, the desired protective and reflective coatings are applied by the vacuum-deposition process. Typical coatings that have been tried experimentally include in this order SiO protective layer, Al reflective layer, a second SiO layer to produce a protective sandwich for the aluminum reflective layer, and a conductive or sensitizing layer such as silver, copper or nickel, as the basis for subsequent electroforming. A number of samples have been produced on which electroforms of both nickel and copper have been electrodeposited to the thickness required for reflective-face skins. After parting, the original silver or copper parting layer is removed from the front surface of silicon monoxide, leaving the completed mirror with coatings firmly adherent. This process has great promise since the reflective coatings are completely protected and the mirror is essentially complete upon removal from the master. No possibility of staining or lack of adhesion due to poor cleaning prior to normal reflective film deposition exists. There are certain problems associated with this technique, however, and for large size concentrators the facility requirements necessary to put down these selected films in a controlled manner on the master are severe. This work will be continued for the duration of the program however, since, if successful, this method is highly desirable as an ultimate fabrication technique.

4.1.3 Coating Adhesion and Durability Studies

The normal test for adhesion of vacuum-deposited coatings is the "Scotch Tape" test. In this test a freshly exposed surface of the adhesive side of cellophane tape is applied to the coated surface and pressed firmly into place. The tape is then jerked away rapidly, exerting maximum pull on the coating. This is a relatively severe test, and if the coatings remain intact and do not come off with the tape, the coating is considered to be firmly adherent. A number of alternative methods for testing the durability of films have been investigated but none appear to be practical to measure the small variations in adhesion that may exist. All of the tests appear to be "go-no-go" devices. Since this "Scotch Tape" test appears to be a standard method for testing coatings within the optics industry, it was employed for testing the adherence of coatings produced on the current program. It is hoped that additional and improved adherence testing techniques may be developed in the future.

The samples of the various reflective coatings that were produced were exposed to different environments to determine their durability. One area of prime concern is the possible degradation due to thermal cycling, and exposure to elevated temperatures. As a preliminary measure of the durability of coatings under temperature extremes and thermal cycling, a test was devised in which the samples were placed in an oven that was cycled from ambient to 500°F with a six hour cool-down to ambient.

One each of the coated samples has been exposed to this type of thermal cycling. A normal atmospheric environment was used for these tests. The test apparatus is such, however, that controlled atmospheres can be employed if desirable.

The unprotected silver surfaces degraded very rapidly due to temperature cycling and, in the case of silver on an electroformed copper substrate, the reflective surface completely degraded in a very short number of cycles. It was also determined that the presence of silver as one of the underlying coatings caused a more rapid degradation than occurred in samples from which the silver had been stripped prior to application of the reflective and protective coatings. After approximately one week of testing, definite degradation around the edges and at places where pin-holes existed was noticed in the surfaces on which the silver undercoat remained. No visible change occurred to the samples from which the silver undercoat had been stripped before coating. Adhesion remained good throughout the testing. Reflectivity tests were repeated on the samples that had been exposed to temperature cycling and the resultant reflectivity values are shown in Table 4-I. In some instances the samples warped causing an inability to obtain accurate reflectivity information. Where necessary, testing will be repeated to validate prior results.

Additional samples of each of the coatings were exposed to outside environment by placing them on the roof of the building for an extended period of time (see Fig. 4-2). This is, of course, rather severe exposure compared to normal storage and handling conditions. However, during extended periods of performance testing, exposure to smog, dust particles, and other air-born contaminants is common. These samples will also be tested for reflectivity to determine amount of degradation near the conclusion of the program.

The fourth sample of each of the coatings was intended to be tested using a standard salt spray test. These facilities are not immediately available at Electro-Optical Systems, Inc., however, and due to the costly nature of establishing the necessary test equipment, these tests will be delayed until the more promising coating combinations are determined. At this time, these samples will be subjected to salt spray tests either at EOS or at an outside vendor.

As previously mentioned, both chromium and rhodium protective overcoatings appeared to give maximum protection against degradation due to exposure, cleaning, handling, etc. Their reflectivity characteristics are, however, somewhat lower than for silver or aluminum surfaces. The basic reflectivities of rhodium and chromium surfaces are shown in Fig. 4-3 over a wide variety of wavelengths. The reflectivity of both of these materials can be increased considerably by use of reflectivity increasing film combinations of pairs of dielectric films such as CeO_2 and MgF_2. No reflectivity information is available on these combinations at this time.

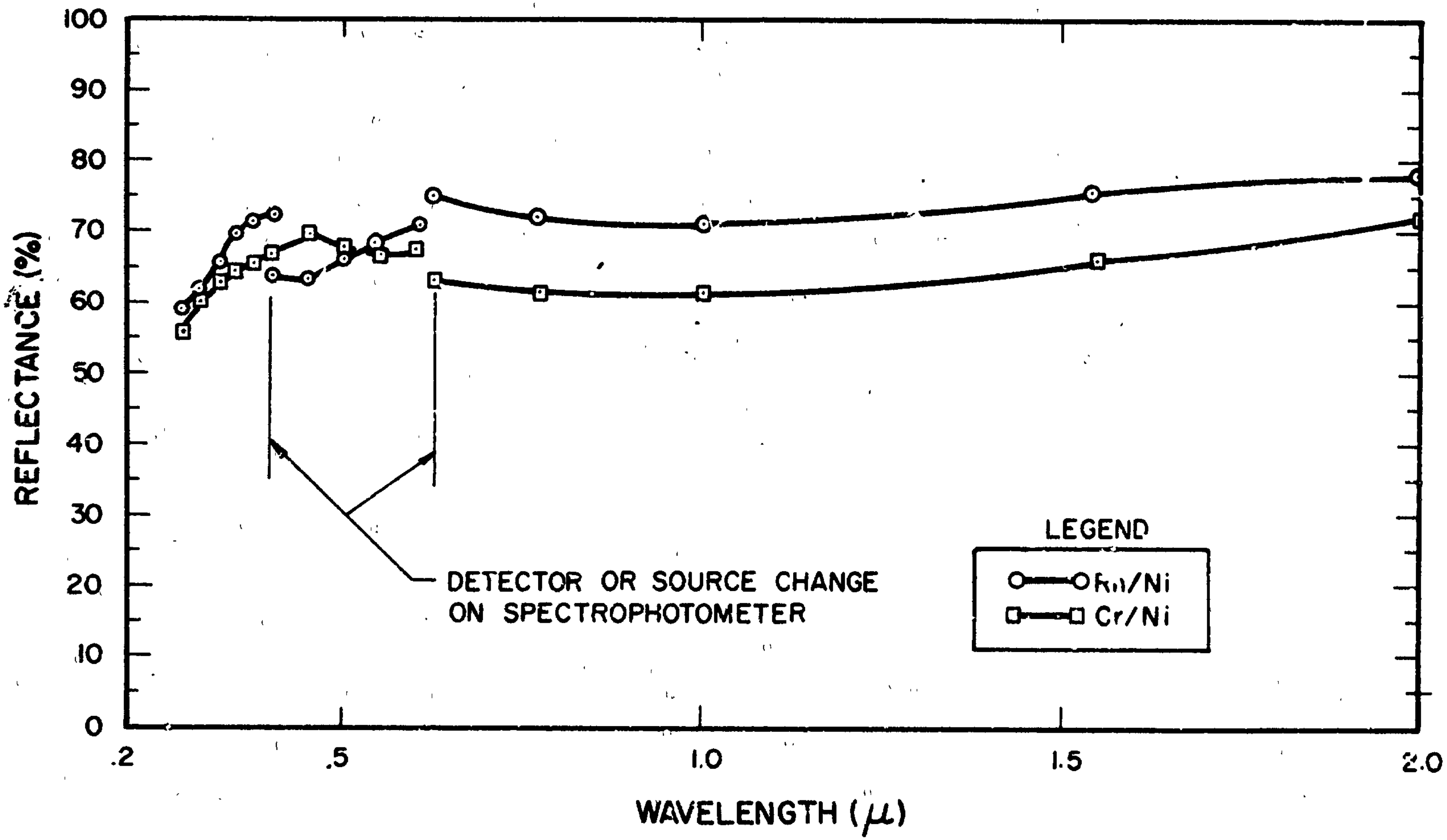

FIG. 4-3 REFLECTIVITY OF RHODIUM AND CHROME SURFACES ON NICKEL

4.1.4 Methods of Protection and Cleaning

During exposure of the reflective surfaces to test conditions and storage for prolonged periods of time, it became evident that cleaning procedures must become established which would not materially degrade the reflective qualities of the concentrator surfaces. The various dielectric films or overcoating with SiO offer substantial protection. Surfaces so treated can be washed or wiped as long as care is exercised to prevent definite abrasion. Unprotected surfaces of silver or aluminum can be carefully wiped with detergent and in some cases even polished with chalk or rouge to bring the reflectivity back up to the original value. It has been determined that silver surfaces can be cleaned a number of times to restore reflectivity and, although numerous visible sleaks appear due to the cleaning operation, the reflectivity values and performance values are not appreciably affected by the multiple cleaning operations. There is no doubt that these sleaks and minute scratches would cause a degradation in the specular characteristics for the shorter wavelengths but there appears to be no appreciable degradation of performance as related to solar concentration.

Consideration is being given to the possibility of coating the as-formed silver surfaces with a material that will evaporate or sublime under space conditions. This would allow protection of the silver reflective surfaces during handling and storage and through launch conditions until the normal earth environment (which appears to be the degrading factor relative to the reflective qualities of the silver surfaces) is left behind. The subsequent evaporation or sublimation of the protective layer would leave an exposed silver surface having maximum reflective properties.

4.2 Application of Protective Coatings

It has become evident from the experimental work performed to date that the techniques required for application of reflective and protective layers by the vacuum-deposition process is not the same for electroformed substrates as for glass. Much of the information available concerning cleaning, maximum adhesion, etc. is based on application of coatings to glass, quartz, or other similar materials. Certain modifications or deviations are required for the application of satisfactory coatings to electroformed metal mirrors.

4.2.1 <u>Pre-treatment, Cleaning, Etc.</u>

The possible future development of predeposited coatings (which will permit the formation and removal of electroformed mirrors from the master complete with reflective and protective coatings) may eliminate the need for involved pre-treatment and cleaning techniques. In the meantime, however, it is necessary to develop techniques and processes to insure that the required subsequent coatings are firmly adherent to the reflective face. Studies are continuing to determine the best method of cleaning the metal face prior to vacuum deposition of the coatings. To date, the most effective treatment involves preliminary cleaning with solvent, detergents, etc., followed by a vapor degrease cycle in which any one of a number of solvents may be employed. It is hoped that, during the remainder of the program, exact requirements for pretreatment and clearing can be established upon a process basis. After the chemical cleaning processes, it appears necessary to use the glow discharge or ion bombardment technique for final cleaning in the vacuum chamber prior to actual deposition of the reflective coatings. Preliminary tests have also indicated that deposition of an evaporated layer of chromium prior to deposition of the subsequent reflective and protective layers materially increases adhesion. On samples produced by this method as well as on larger mirrors (if precleaning and glow discharge techniques were correct) complete adhesion was evident. In instances where the chromium layer was not applied it was possible to remove the reflective layers using the "Scotch Tape" test.

4.2.2 <u>Facility Requirement</u>

EOS is currently in the process of installing a vacuum-coating facility that will include an 18-inch experimental Bell Bar and a 54-inch diameter coating tank and related equipment.

Consideration is being given to increasing the size of the installation to 72 inches so that 60- inch diameter mirrors and masters can be accommodated. In any event, in-house facilities will greatly improve the control required throughout the cleaning and coating processes so that maximum knowledge of techniques and facility requirements can be gained.

One of the objectives in this phase of the program is to determine what facilities, special tooling, techniques, etc. are required for the satisfactory application by vacuum deposition of the necessary reflective and protective coatings. A discussion of facility requirements and associated techniques will be included in the final report.

5. SUMMARY

The experimental studies relating to control of the various bath parameters and techniques will be more fully developed during the succeeding portion of this program. Although experimental fabrication has been started on the 5-foot diameter concentrator, the final units that will demonstrate the best design concept and technique will be made relatively late in the program. This timing allows for maximum development of techniques and processes and it is felt that highly satisfactory concentrators will result. Coating studies should also be concluded by that time. In-house coating capabilities (aided by the installation of the EOS vacuum-coating facility) will be maximized so that the reflective and protective coatings applied to the final concentrators should be fully representative of the most desirable combination achievable with present concepts.

As stated previously, integration of concentrator design with power-system design indicates that peripheral-torus or monocoque-support is more desirable than center-mounted concentrators from the standpoint of stability, weight and many other considerations, at least for concentrator sizes that are compatible with one-piece design. Additional design and evaluation efforts (which, it is hoped, will be aided by shake and vibration information obtained from Jet Propulsion Laboratory testing of concentrators produced on the prior program) will be included in greater detail in the final technical report. An evaluation of the various parameters and their relationships for application to larger concentrator diameters will also be included in the final report.

Development of copper with improved physical properties and the controls associated with reproducible electroforming of this material, together with investigations of other possible electroforming materials of a nonmagnetic nature will, it is hoped, make practicable the fabrication of nonmagnetic concentrators by the electroforming process.

Testing techniques were developed extensively during the prior program and no major changes are contemplated in test methods or equipment. Improvements and upgrading of the Electro-Optical Systems testing facility are regularly made and it is planned that extensive optical and performance testing can be achieved on the 5-foot diameter concentrators before delivery to Jet Propulsion Laboratory for further testing.

At the end of the first five-months' period, essentially all areas of activity are on schedule as outlined in the basic program schedule (Fig. 1-1) and no difficulty is anticipated in completing all areas of activity in the manner in which they were originally programmed.